High-resolution monthly temperature and salinity climatologies for the northwestern North Atlantic Ocean

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Canadian Data Report of Hydrography and Ocean Sciences

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The correct citation for data reports appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Data reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Regional and headquarters establishments of the former Ocean Science and Surveys sector ceased publication of their various report series in December 1981. A complete listing of these publications and the last number issued under each title are published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 38: Index to Publications 1981. The current series began with Report Number 1 in January 1982.

Rapport statistique canadien sur l'hydrographie et les sciences océaniques

Les rapports statistiques servent de véhicule pour la compilation et la diffusion des données sous une forme directement utilisable par les scientifiques et les ingénieurs. En général, les rapports contiennent des données brutes ou analysées mais ne fournissent pas d'interprétations des données. Ces compilations sont préparées le plus souvent à l'appui de travaux reliés aux programmes et intérêts des secteurs des Océans et des Sciences de Pêches et Océans Canada.

Le titre exact des rapports statistiques figure au-dessus du résumé de chaque rapport. Les rapports statistiques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports statistiques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page de titre.

Les établissements de l'ancien secteur des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du rapport numéro 1 en janvier 1982.

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ABSTRACT

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Temperature and salinity data from the hydrographic data base at Bedford Institute of Oceanography are objectively analyzed to produce monthly climatologies at 33 depths on a $1/6^0$ x $1/6^0$ grid. The area of coverage is $35^0 - 80^0$ N, $40^0 - 100^0$ W, which includes Baffin Bay, the Labrador Sea, Hudson Bay, N.E. Newfoundland Shelf, the Grand Banks, Newfoundland Basin, the Gulf of St. Lawrence, Scotia Shelf, the Gulf of Maine and the Gulf Stream region. The analysis used an iterative difference-correction procedure with topography dependent domains of averaging. Horizontal contour plots of the analyzed temperature and salinity fields at selected depths are presented.

RÉSUMÉ

Tang, C.C.L, 2007. High-resolution monthly temperature and salinity climatologies for the northwestern North Atlantic Ocean. Can. Data Rep. Hydrogr. Ocean Sci. No.169: iv + 55 pp.

Les données sur la température et la salinité de la base de données hydrographiques à l'Institut océanographique de Bedford sont analysées de façon objective afin de produire des climatologies mensuelles à 33 profondeurs sur une grille de $1/6^o$ sur $1/6^o$. La zone de couverture est $35^o - 80^o$ N et $40^o - 100^o$ O, ce qui comprend la baie de Baffin, la mer du Labrador, la baie d'Hudson, la plate-forme du nord-est de Terre-Neuve, les Grands Bancs, le bassin de Terre-Neuve, le golfe du Saint-Laurent, le plateau néo-écossais, le golfe du Maine et la région du Gulf Stream. L'analyse a consisté en l'utilisation d'une procédure itérative de correction des différences avec domaines d'établissement de moyennes dépendants de la topographie. Des tracés de contours horizontaux des champs de température et de salinité analysés aux profondeurs choisies sont présentés.

1. Introduction

Over the past 20 years, several temperature and salinity climatologies of the world ocean have been produced (Levitus, 1982; Conkright et al., 1998; Conkright et al., 2001; Locarnini et al., 2006). The horizontal resolution of these data sets is typically 1^0 in latitude and longitude. Such a resolution cannot resolves small-scale features in coastal oceans such as sharp front over the shelf break, and is inadequate for regional-scale modeling. A high-resolution seasonal data set for the northwestern North Atlantic Ocean ($1/6^0$ x $1/6^0$) has been compiled by Tang and Wang (1996) to meet the needs of regional modeling. The monthly data set described in this report is a follow-up of the seasonal data set. In the report, the method of analysis is explained and the temperature and salinity fields from the analysis at selected depths are presented.

2. Data source

The data used in the analysis were taken from the hydrography data base at Bedford Institute of Oceanography. The data set encompasses the entire eastern Canadian seaboard and has a temporal coverage from 1910s to the present. The sources of the data base include Marine Environmental Data Service (MEDS) of Canada and National Ocean Data Center (NODC) of U.S..

In this work, data from the earliest date to 2005 in an area bounded by the 35^0 N, 80^0 N, 40^0W and 100^0 W latitude/longitude lines were retrieved for analysis.

3. Method of analysis

The method of analysis is a modification of the iterative difference-correction procedure developed by Levitus (1982) for the world ocean in which the domains of averaging are circular areas. In this analysis, depth dependent domains of averaging were used to reflect the anisotropic nature of the temperature and salinity fields, in particular, over steep slopes. The analyzed data were given on a $1/6^0$ x $1/6^0$ grid at 32 standard depths (Table 1).

The major steps taken in the analysis are described in the following sub-sections.

(a) Data preparation and range check

Duplicate stations in the data base, and stations with data values outside the ranges 26 $^0/_{00}$ ~ 38 $^0/_{00}$ for salinity and -2^0C ~ 35^0C for temperature were removed. This process eliminates stations with large measurement errors and stations located in rivers and upper estuaries.

(b) Sorting of raw data into monthly bins

The raw data for each month were sorted into bins of $1/12^0$ x $1/12^0$ cells and 33 depth segments. The depth range for each segment is given in Table 1. The exceptions were data

of the winter months (January, February, March) at 4500 m and 5000 m, for which the three months' data were combined to increase the data density. Data in a given bin are considered to be located at the center of the cell and at the standard depth for the horizontal analysis described in sub-section **(d)**. For each bin, the mean temperature and salinity in given years and months were calculated first. The means were then averaged over different years to produce the final means for each bin. Such a two-step averaging is necessary in order to remove the bias caused by the unevenly distribution of the data points over the years.

To obtain a good estimate of the means in a given $1/12^0$ x $1/12^0$ cell, the mean and standard deviation were calculated first from the raw data. Data points with extreme values lying outside the range (mean $\pm$ 3 standard deviation) were discarded and the mean was re-calculated. The procedure was repeated until all data values were within the tolerance limits. The final mean was used in the vertical interpolation described below.

(c) Vertical interpolation

Small data gaps in the vertical were filled by averaging the data values at two adjacent standard depths. If both the adjacent depths had no data, the data at the next two adjacent depths were used. If no data were found in these depths, no further interpolation was attempted and the data gap would remain at those depths. Vertical interpolation by this method has the advantage that even if the data have uneven depth distribution, the interpolated data values are constrained by the adjacent values and represent a reliable estimate.

(d) Analysis on the horizontal planes

An iterative difference-correction method was employed to smooth and interpolate the data horizontally. At each standard depth, the data were averaged with a distance and topography dependent weight for each grid point according to the following equation:

$$S = S_{guess} - \frac{\sum_i W_i (S_{guess,i} - S_i)}{\sum_i W_i} \qquad (1)$$

where S_{guess} is the initial guess at a grid point, S_i is the data value and W_i is the weight. The summation is over data points within a given radius of influence and meeting a criterion for water depth.

Over a sloping ocean bottom, the horizontal coherent scale of temperature and salinity in the cross-slope direction is in general smaller that in the along-bottom slope direction. Data at locations with water depths much greater or smaller than the water depth of the grid point should not be included in the summation. This condition is analogous to using anisotropic weights of average, but the computation involved is much simpler. The summation in (1) was applied only to data points satisfying

$$|H - H_i| < \delta h \qquad (2)$$

where H and H_i are the water depth of the grid point and the data point respectively. A depth dependent δh was used to take into account the fact that the variation of water properties is smaller in the deep ocean than in the coastal ocean:

$$\delta h = 500 + 0.14\,H$$

A Gaussian form was used for W_i:

$$W_i = 0, \qquad r_i > R$$

$$W_i = \exp\left(-\frac{4r_i^2}{R^2}\right), \qquad r_i \le R$$

where r_i is the horizontal distance between the grid point and the data point, and R is the radius of influence.

The calculation for S was repeated for three iterations with a decreasing radius of influence. For each iteration, S calculated in the previous iteration was used as the initial guess. For the first iteration, the mean of all data at the same standard depth was used as the initial guess. The radii of influence for the three iterations are set at 800 km, 500 km and 200 km if the depth is equal or less than 1100 m, and 1000 km, 600 km and 400 km if the depth is greater than 1100m.

The data in each iteration must pass a statistical check to ensure extreme data values were not included in the averaging. Data with values outside the range (mean $\pm$ 2 x standard deviation) were removed. This procedure was repeated till all data points were within the tolerance limits.

In the horizontal analysis, a special treatment was applied to Baffin Bay and Hudson Bay. Since the water in Hudson Bay and in Baffin Bay below the sill depth of Davis Strait, 650 m, is not influenced by the Labrador Sea in a significant way, the temperature and salinity analysis in those areas and depths used data within Hudson Bay and Baffin Bay themselves.

(e) Three-dimensional smoothing in areas with sparse data

In areas with sparse data, the temperature and salinity calculated from step ***(d)*** may have large differences between neighboring depths. This is due to the fact that vertical coherence was not taken into consideration in the horizontal analysis. To improve the results, three-dimensional smoothing was applied to the data from step ***(d)*** on a $1/6^0$ x $1/6^0$ grid (every other grid point of the $1/12^0$ x $1/12^0$ grid) for the following months and areas:

Winter (January, February, March): the entire area
Fall (October, November, December): north of 50^0 and water depths greater or equal to 2000 m.

The temperature or salinity value at grid point j, $\overline{S_j}$, was computed from

$$\overline{S}_j = \frac{\sum_i w_i S_i}{\sum_i w_i}$$

where S_i is the horizontally interpolated data value from step ***(d)***. The summation is over data point satisfying (2). The weights, w_i, is given by

$$w_i = \exp\left(-\frac{4r_i^2}{L^2} - \frac{4z_i^2}{D^2}\right), \qquad r_i < R \text{ and } z_i < D$$

$$w_i = 0, \qquad r_i > R \text{ or } z_i > D$$

where r_i and z_i are the horizontal and vertical distances between points i and j respectively, and L and D are the horizontal and vertical coherence scales respectively. The following values were used for L and D:

L = 100 km,	$z_i \leq 1000$ m
L = 200 km,	$z_i \geq 1100$ m
D = 100 m,	$z_i \leq 300$ m
D = 200 m,	$300 \text{ m} < z_i \leq 1300$ m.

For depths greater than 1300 m, only horizontal smoothing with L = 200 km was performed since the change of temperature and salinity in the deep water was very small. Applying a large D would distort the depth variation obtained in the horizontal analysis.

For all the other months and areas, a two-dimensional horizontal smoothing (i.e., $D = \infty$) was used. The main effect is to smooth the contour lines.

(f) Filling holes in the horizontal planes

Holes in the horizontal planes after steps ***(d)*** and ***(e)*** were filled by averaging the data over a $5^0 \times 5^0$ grid. A special treatment is applied to Baffin Bay and Hudson Bay (including Hudson Strait and Foxe Basin) where the water is covered by sea-ice most of the year. In areas with no data in Baffin Bay and Hudson Bay, the grid points have no temperature and salinity

values. The criterion of no data is no data point within $\pm 1^0$ in latitude and longitude from the grid point.

4. Contour plots at selected depths

Contour plots of the temperature and salinity fields at 0 m, 100 m, 500 m, and 1000 m are presented in the pages following Table 1. The binned and vertically interpolated data points on the $1/12^0 \times 1/12^0$ grid are shown as red dots. The purpose is to allow the user to judge whether the analyzed data in a given area are suitable for a particular application. The blue line is the bathymetry contour of the indicated depth. Since the maximum depth of the analyzed data (Table 1) may be greater that the bottom depth, the red dots may appear outside the bathymetry contour, i.e., in Laurentian Channel in the January 500 m map. These points should be ignored in applications.

5. Applications

The monthly temperature and salinity data can be used to study the annual variation of water properties, estimate geostrophic currents, volume/freshwater transports and mixed-layer depth. They can also be used to initialize and validate numerical models. A partial list of research papers using this data set are given in the references section.

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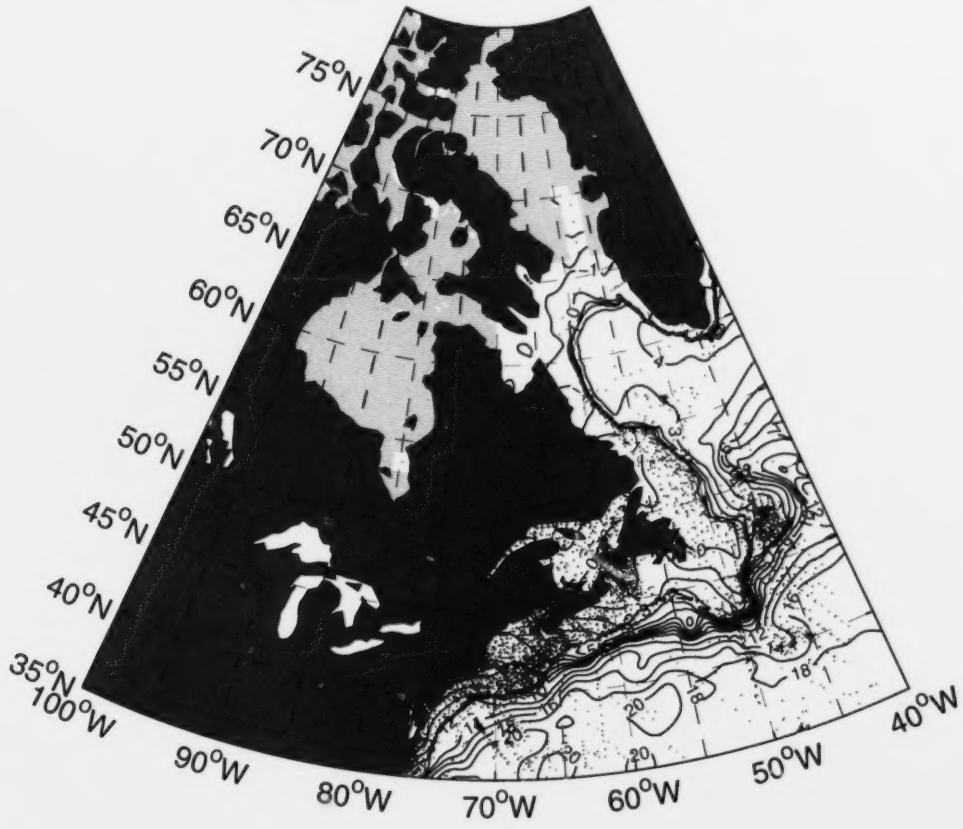
Table 1. Standard depths

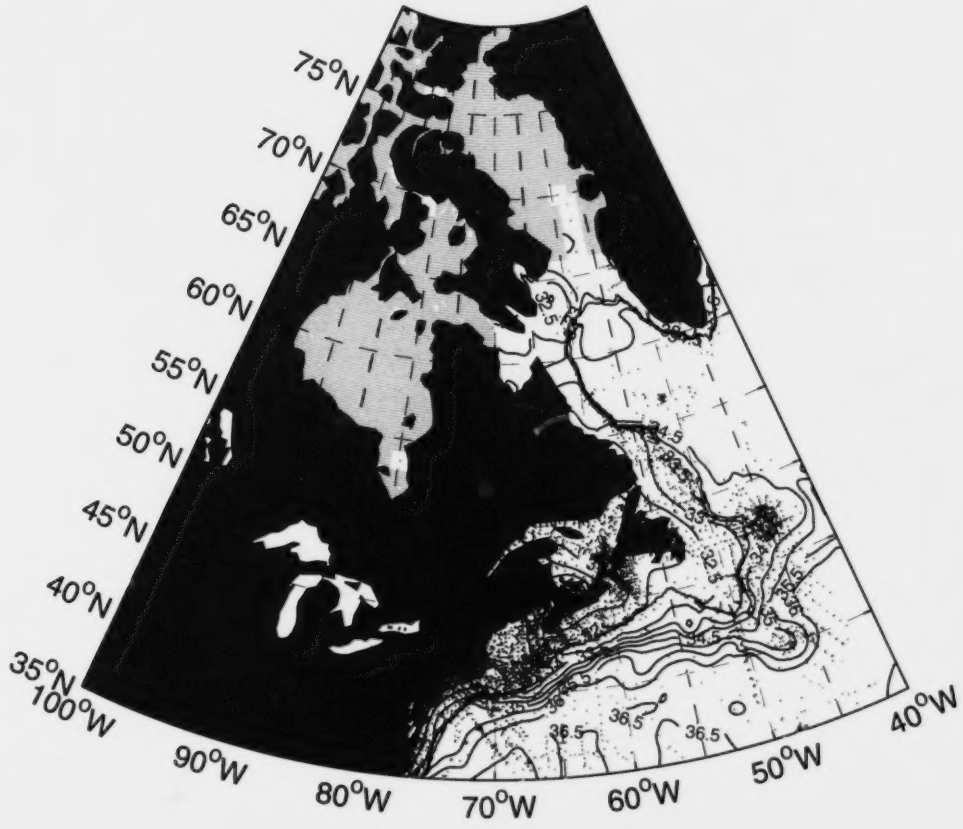
Standard depths (right column) and the associated depth ranges (first and second columns) for the analysis.

DATA DEPTH (m) lower limit	DATA DEPTH (m) upper limit	STANDARD DEPTH (m)
0	5	0
5	15	10
15	25	20
25	40	30
40	62.5	50
62.5	87.5	75
87.5	112.5	100
112.5	137.5	125
137.5	175	150
175	225	200
225	275	250
275	350	300
350	450	400
450	550	500
550	650	600
650	750	700
750	850	800
850	950	900
950	1050	1000
1050	1150	1100
1150	1250	1200
1250	1350	1300
1350	1450	1400
1450	1625	1500
1625	1875	1750
1875	2250	2000
2250	2750	2500
2750	3250	3000
3250	3750	3500
3750	4250	4000
4250	4750	4500
4750	5250	5000
5250	5750	5500

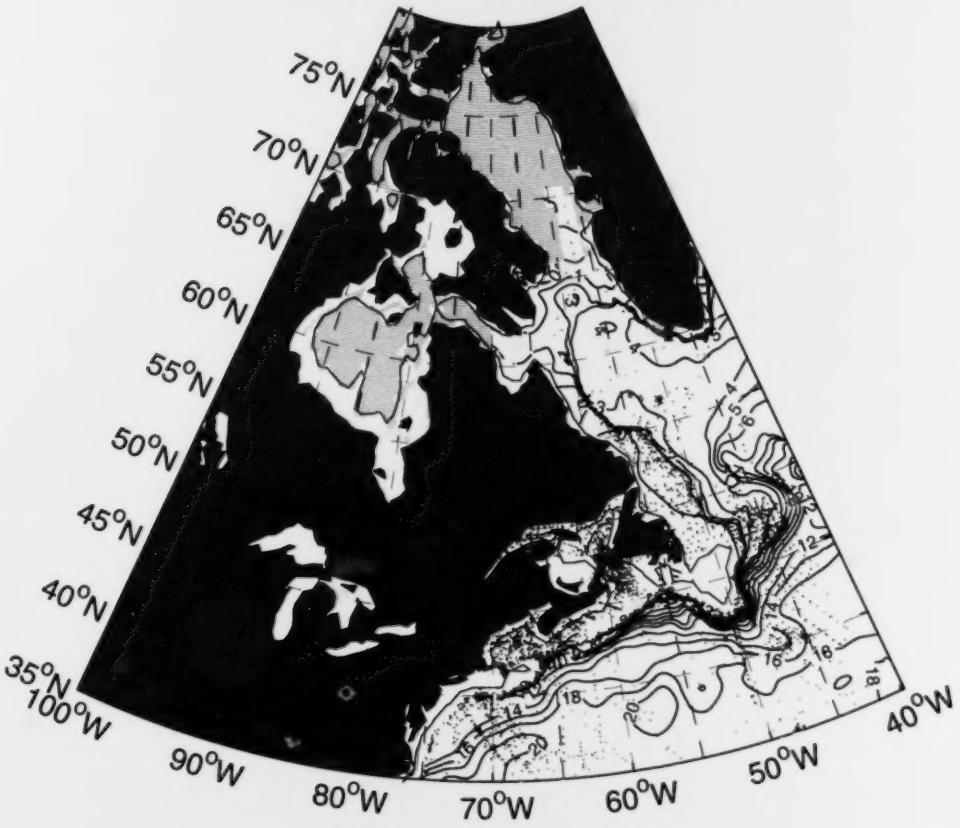
January Temperature at 0m



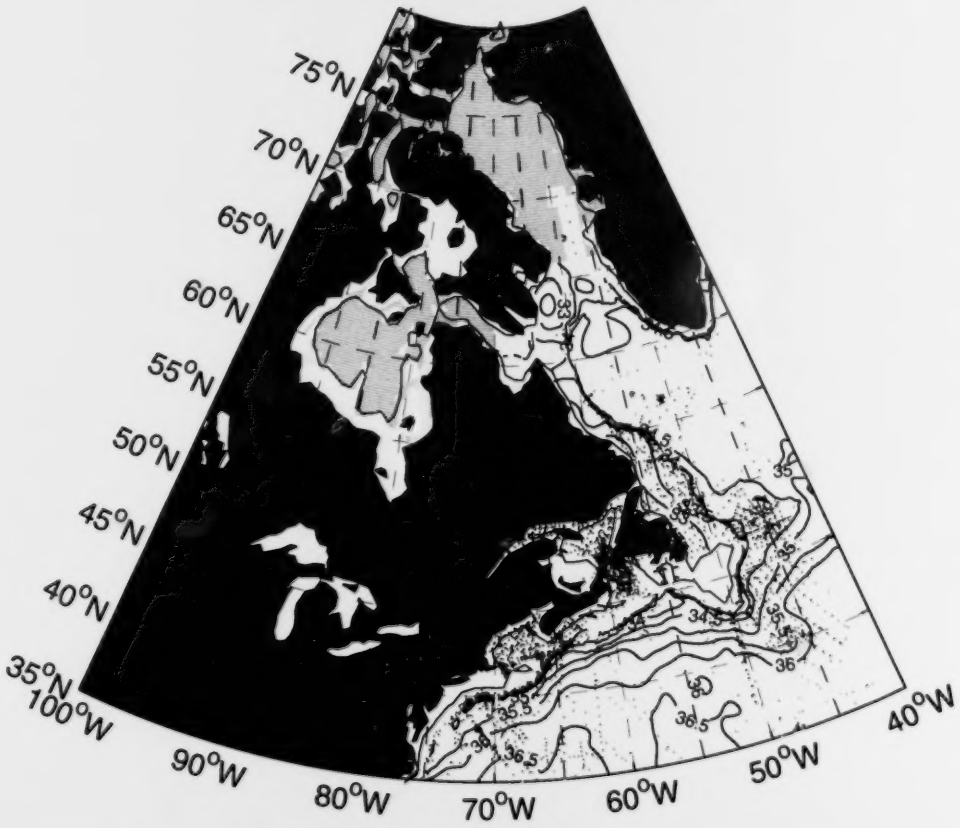
January Salinity at 0m



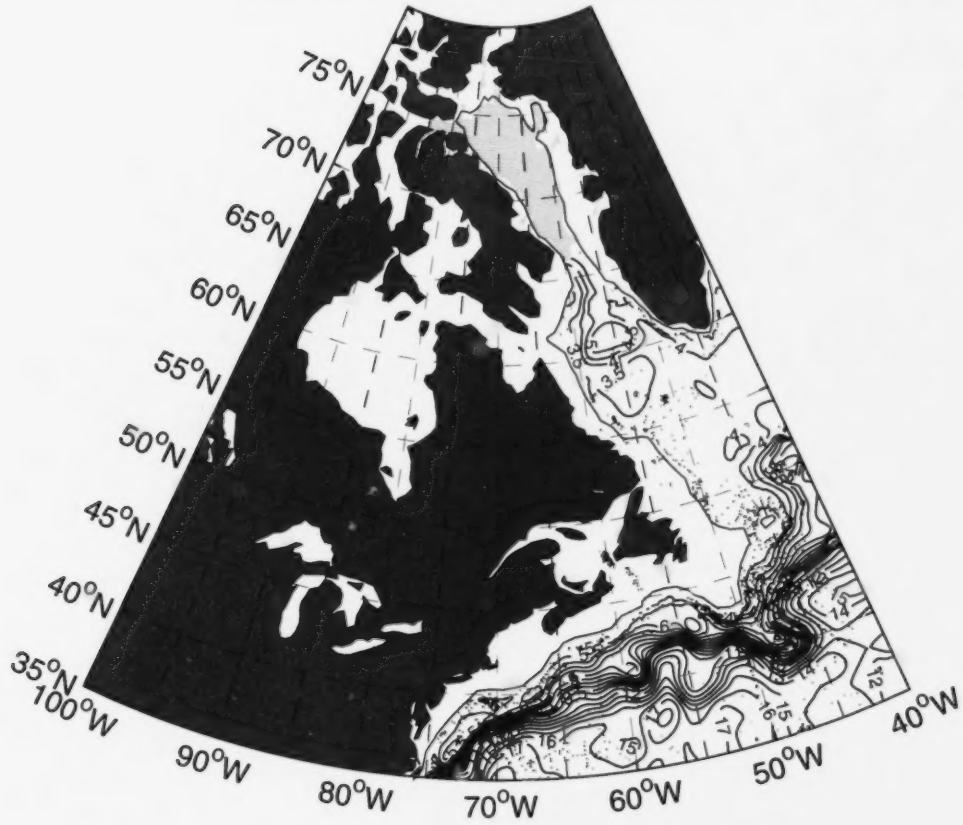
January Temperature at 100m



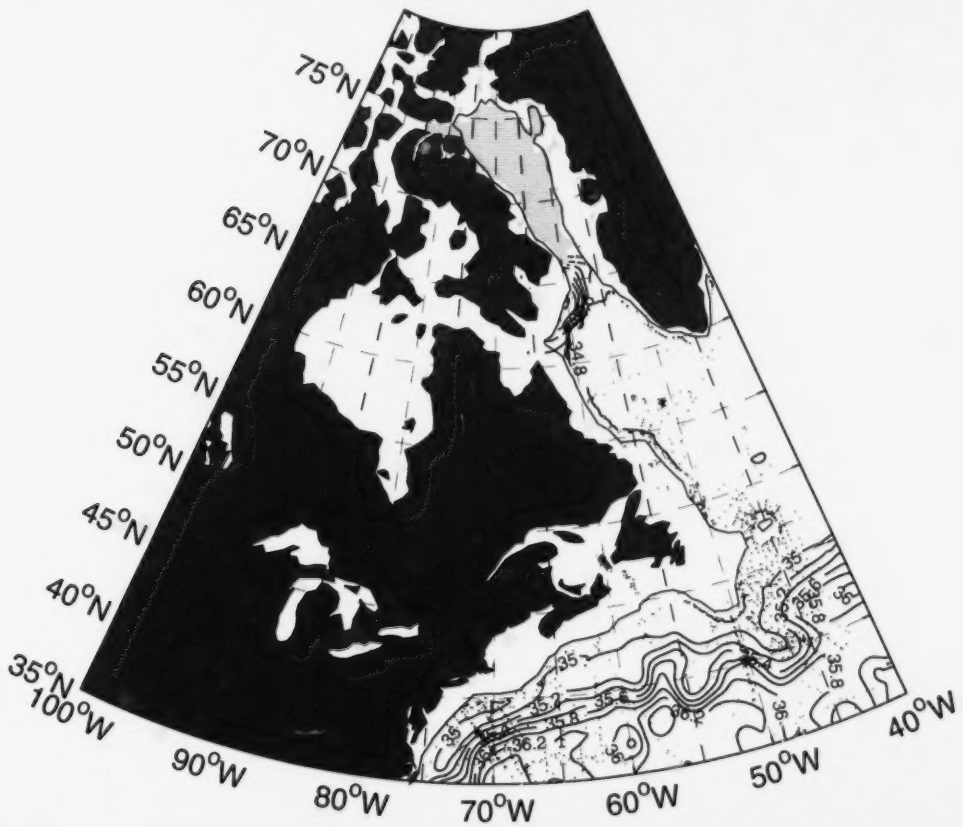
January Salinity at 100m



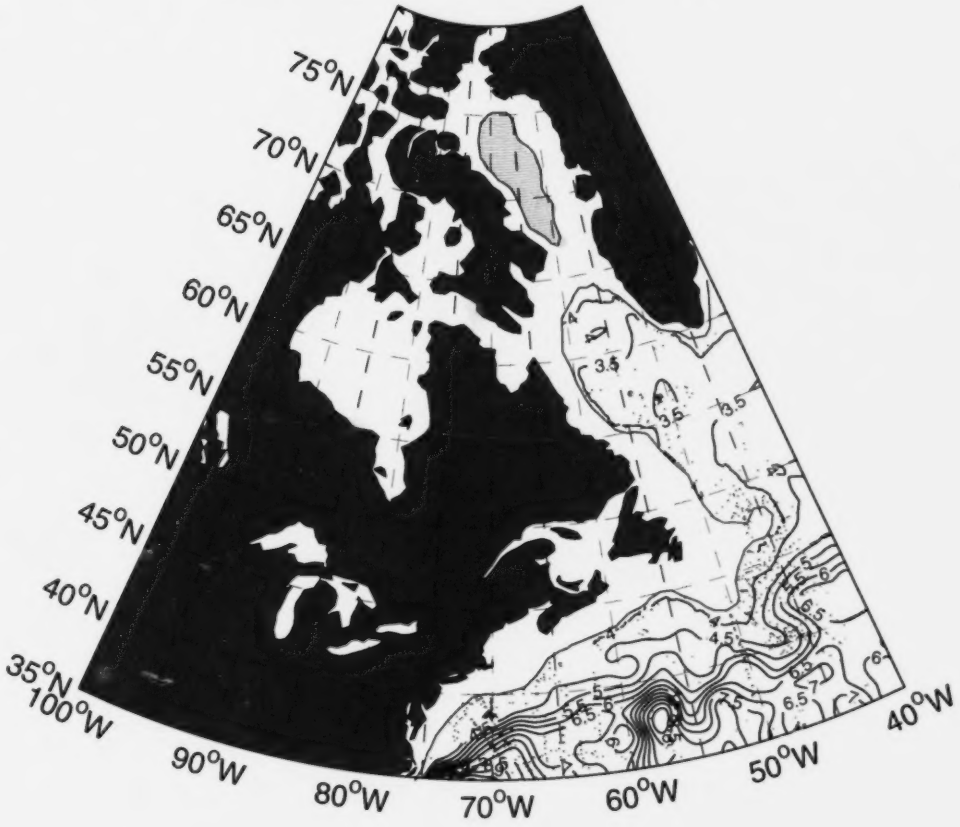
January Temperature at 500m



January Salinity at 500m



January Temperature at 1000m



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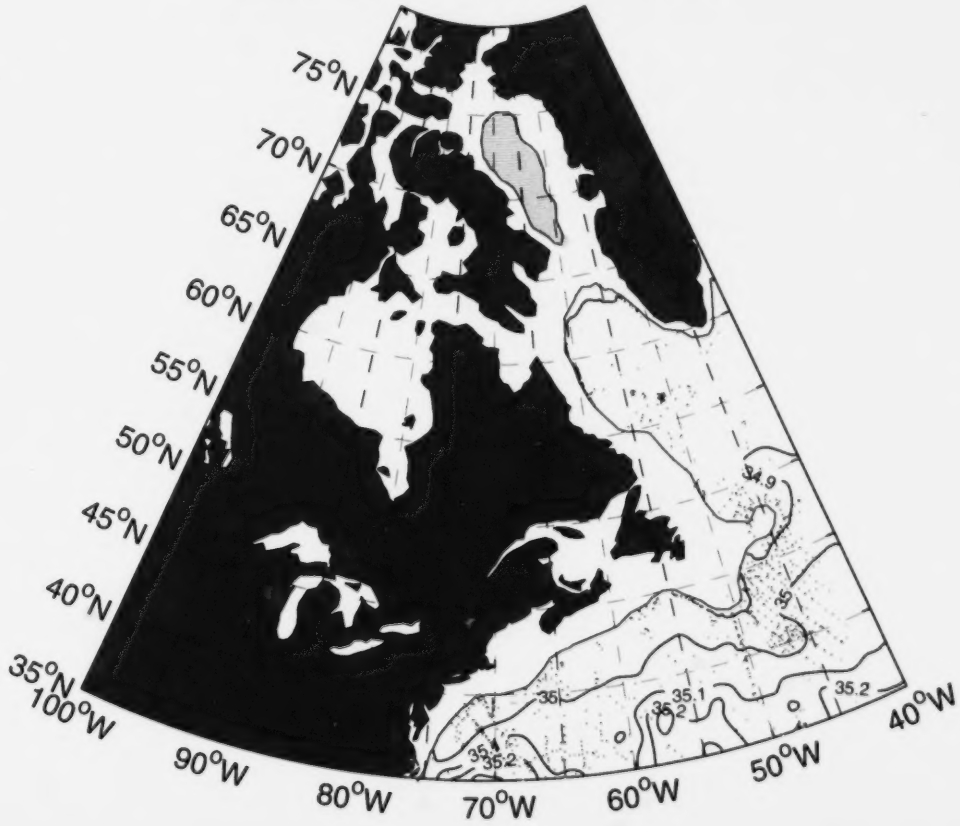

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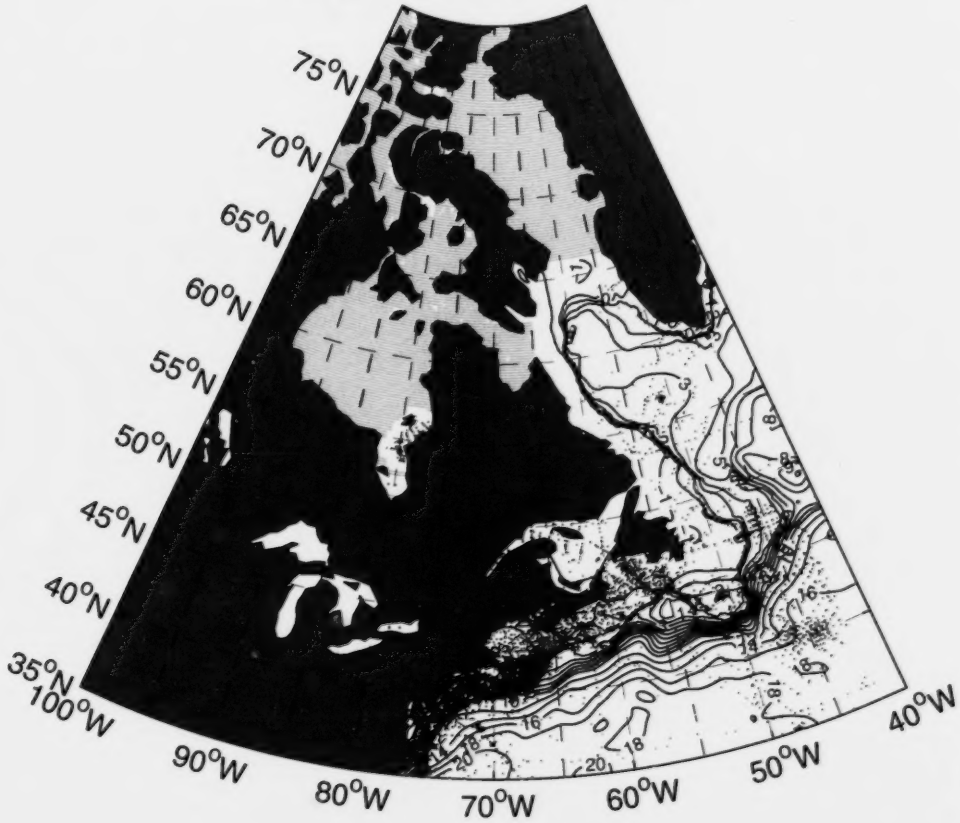

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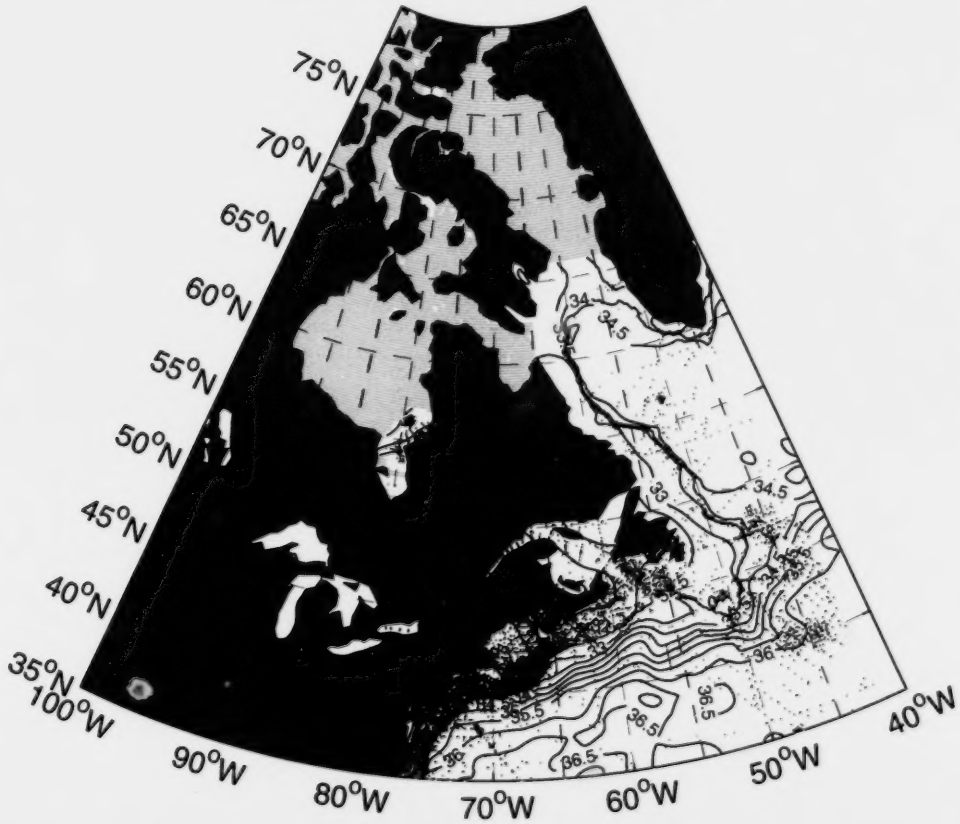
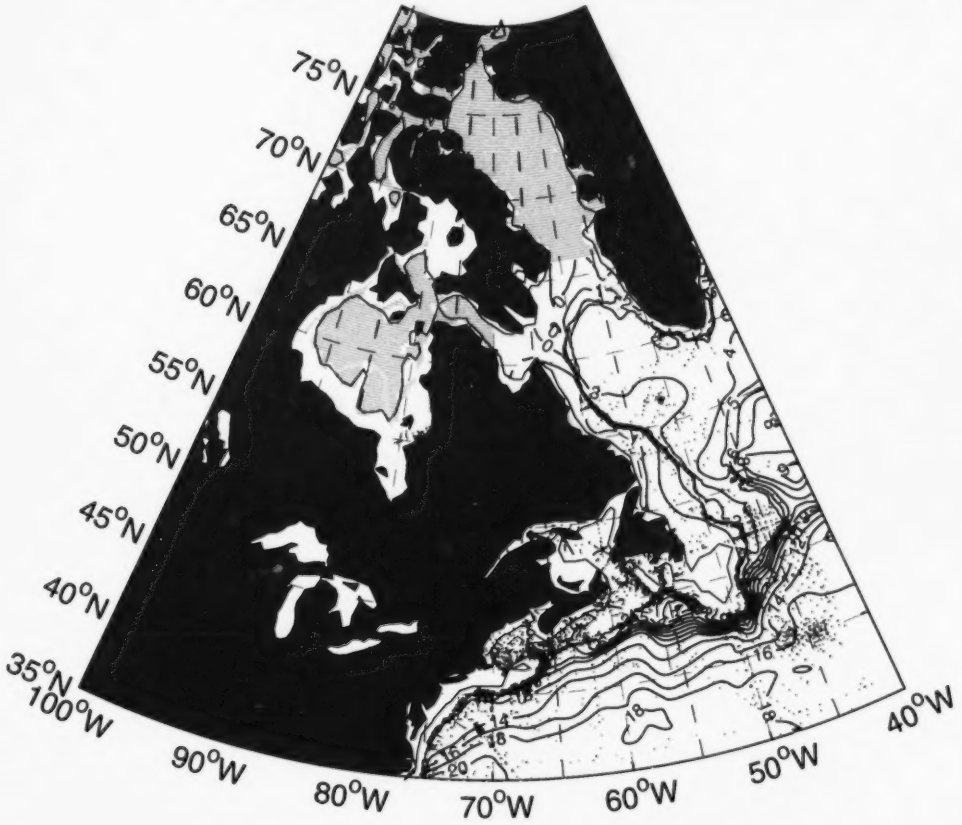


February Temperature at 100m



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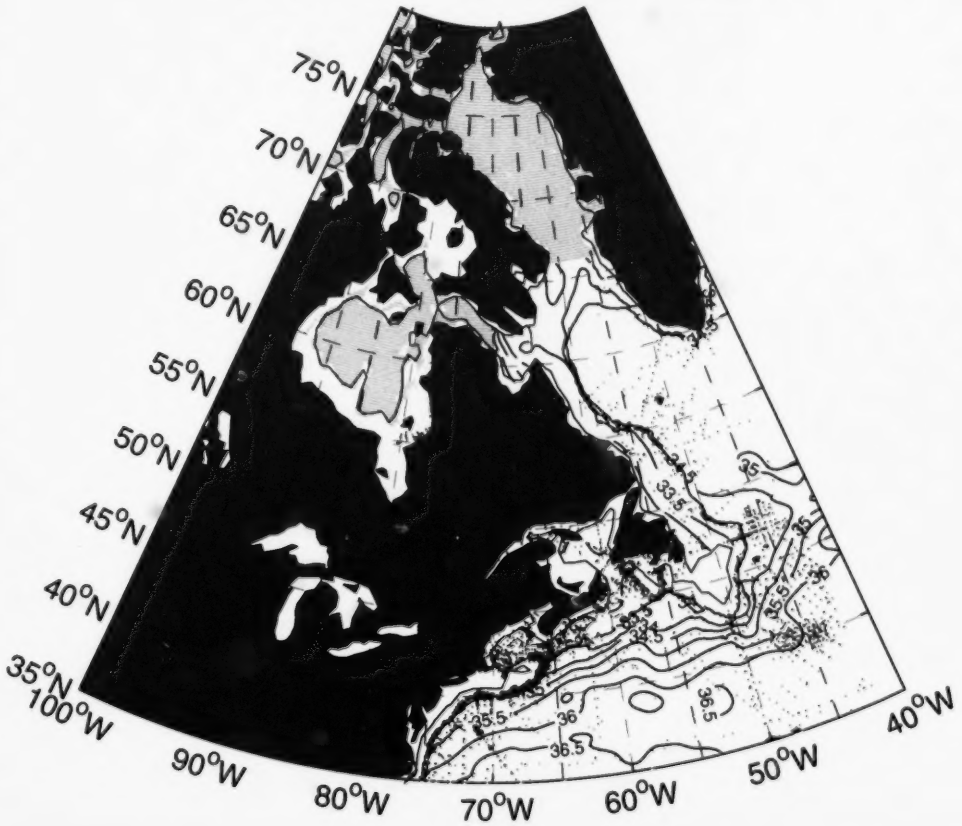

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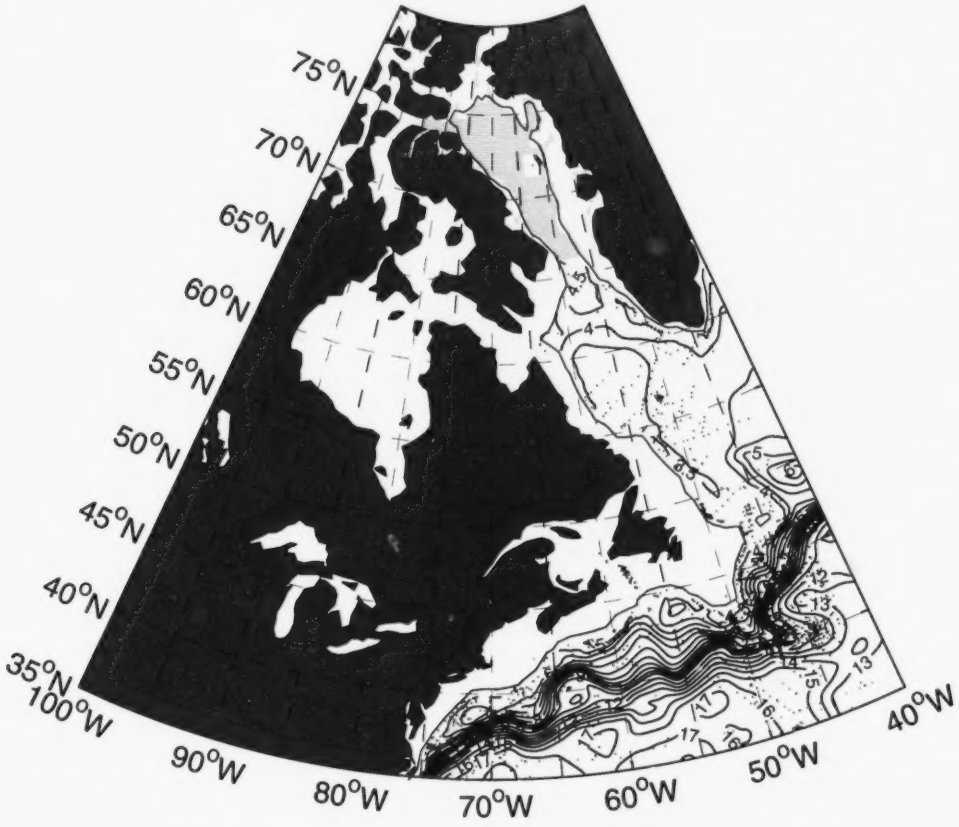

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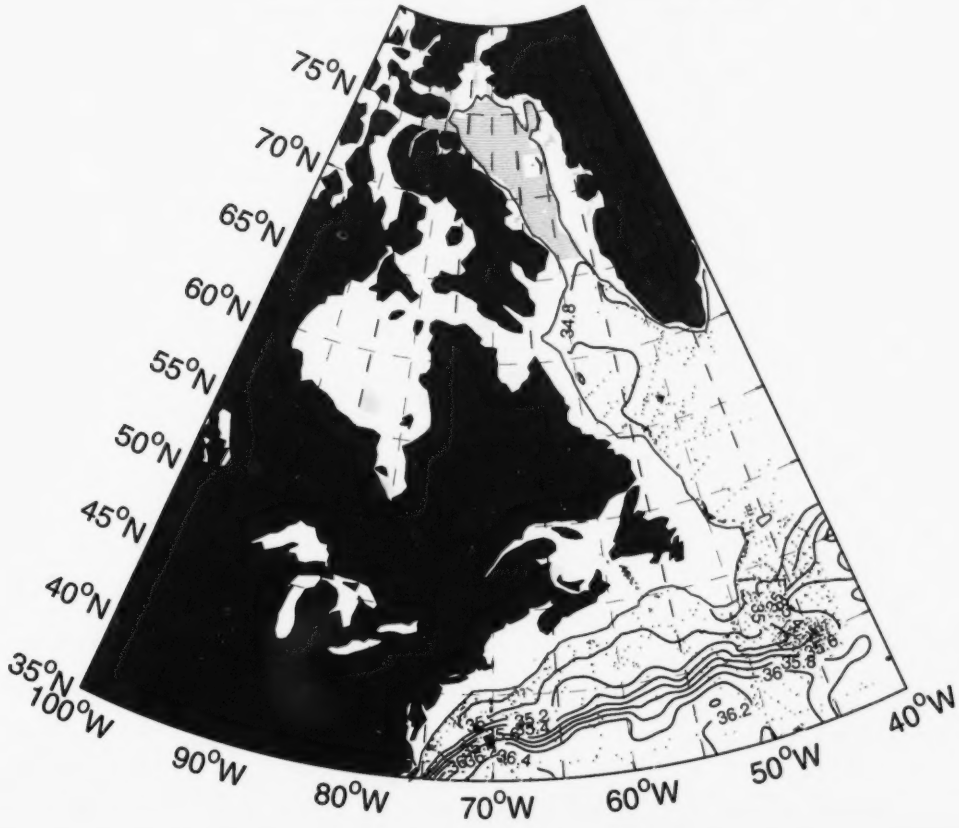
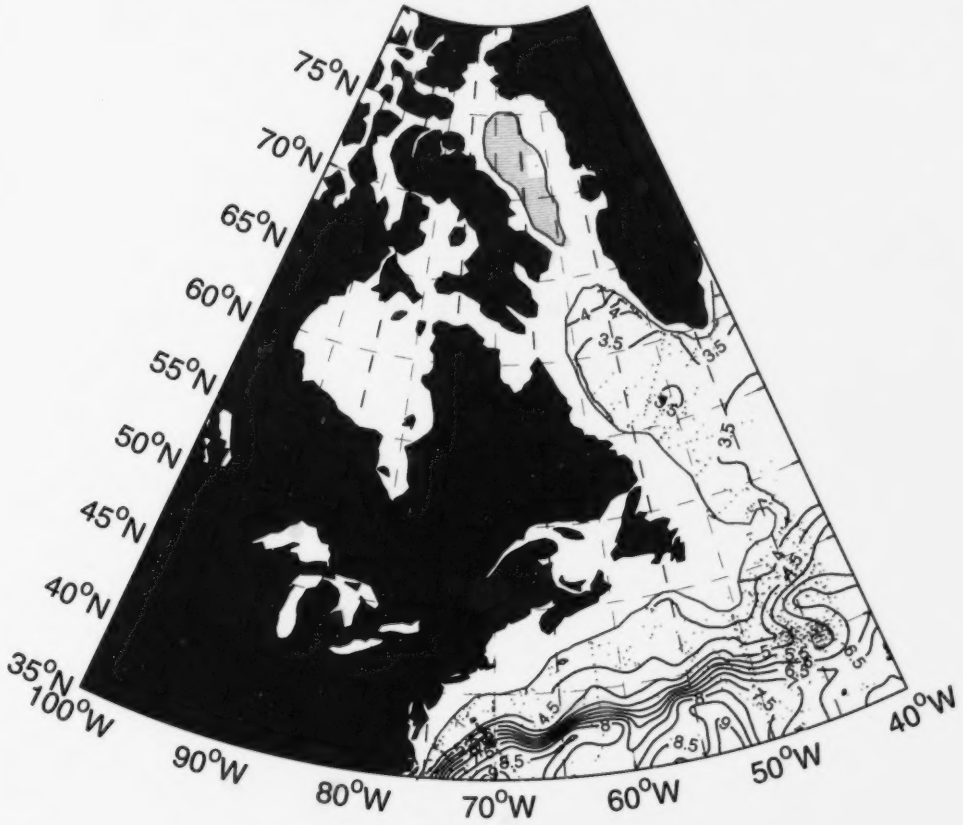
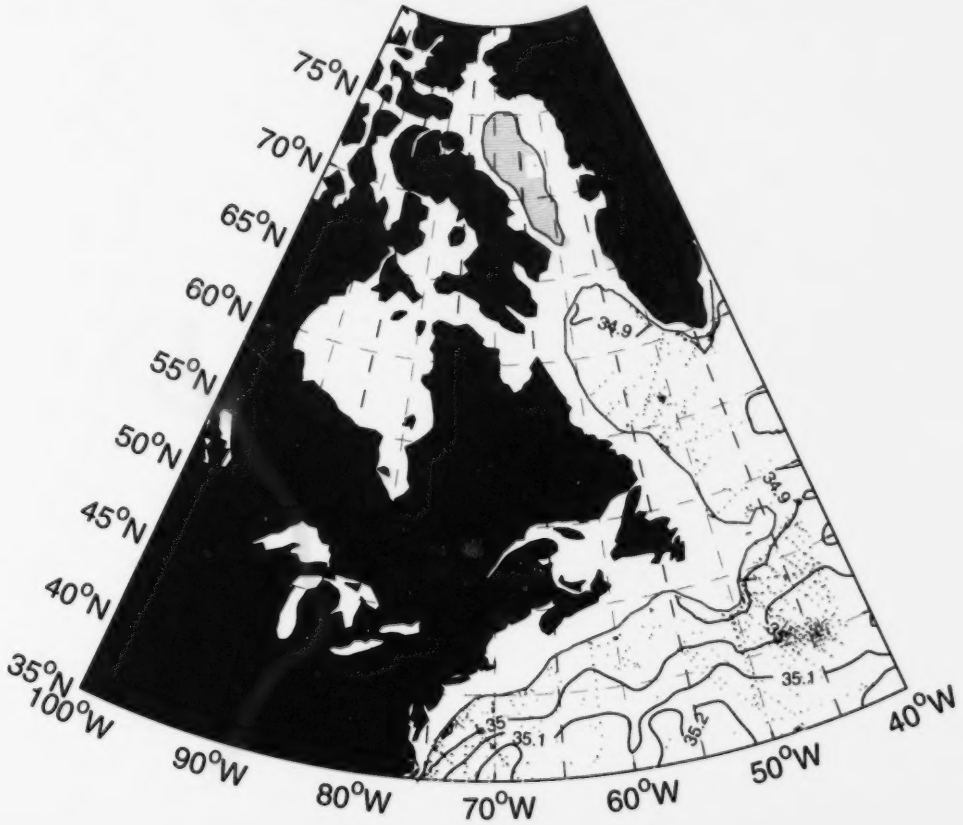


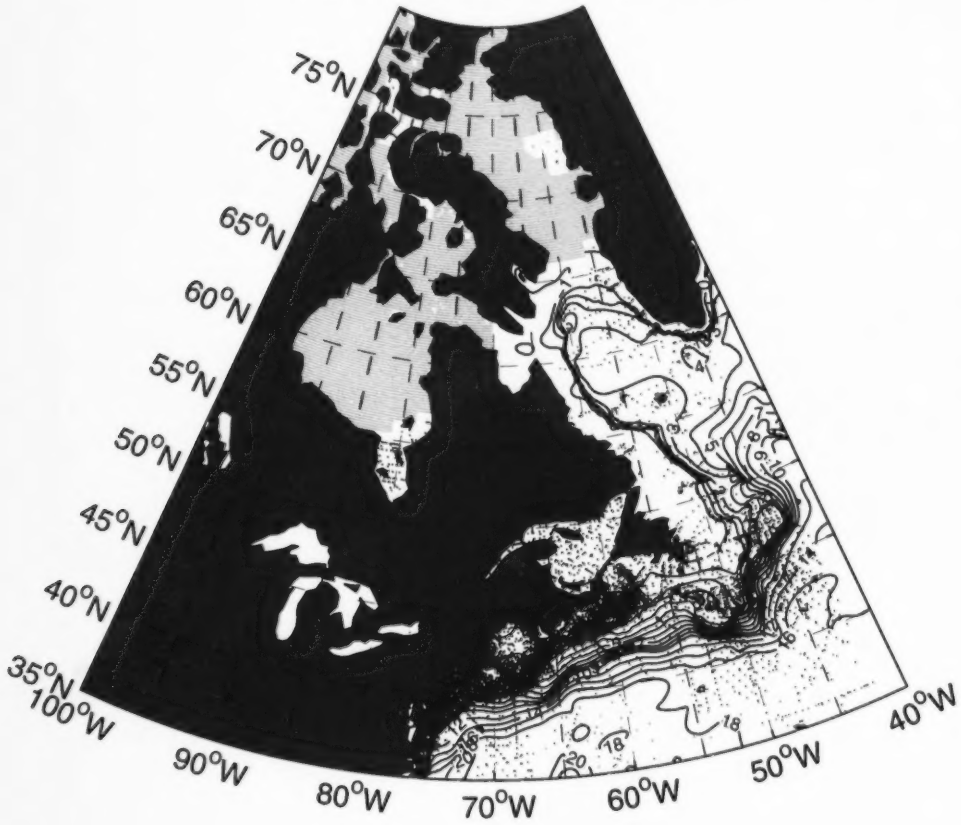
February Temperature at 1000m



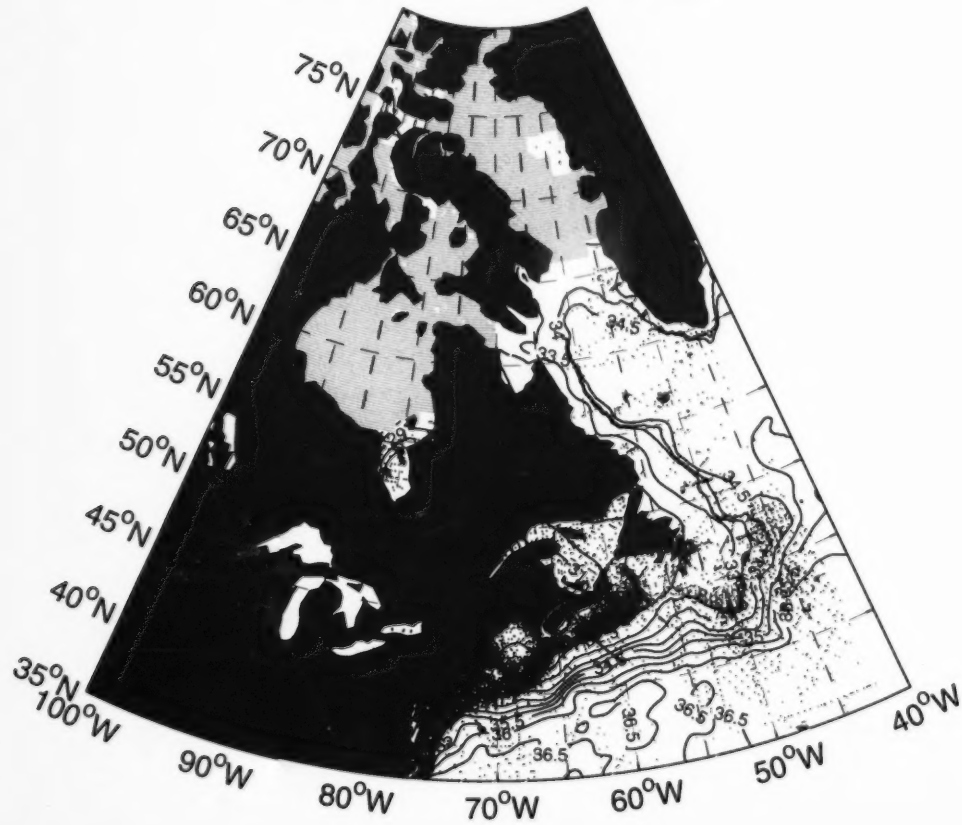
February Salinity at 1000m



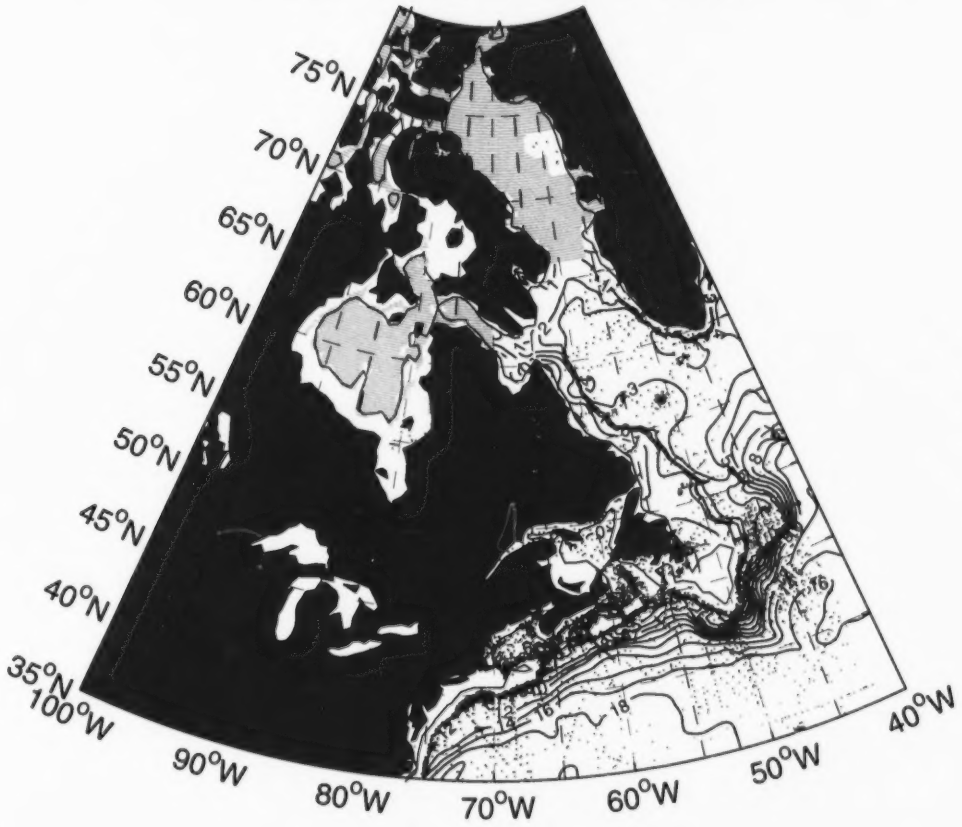
March Temperature at 0m



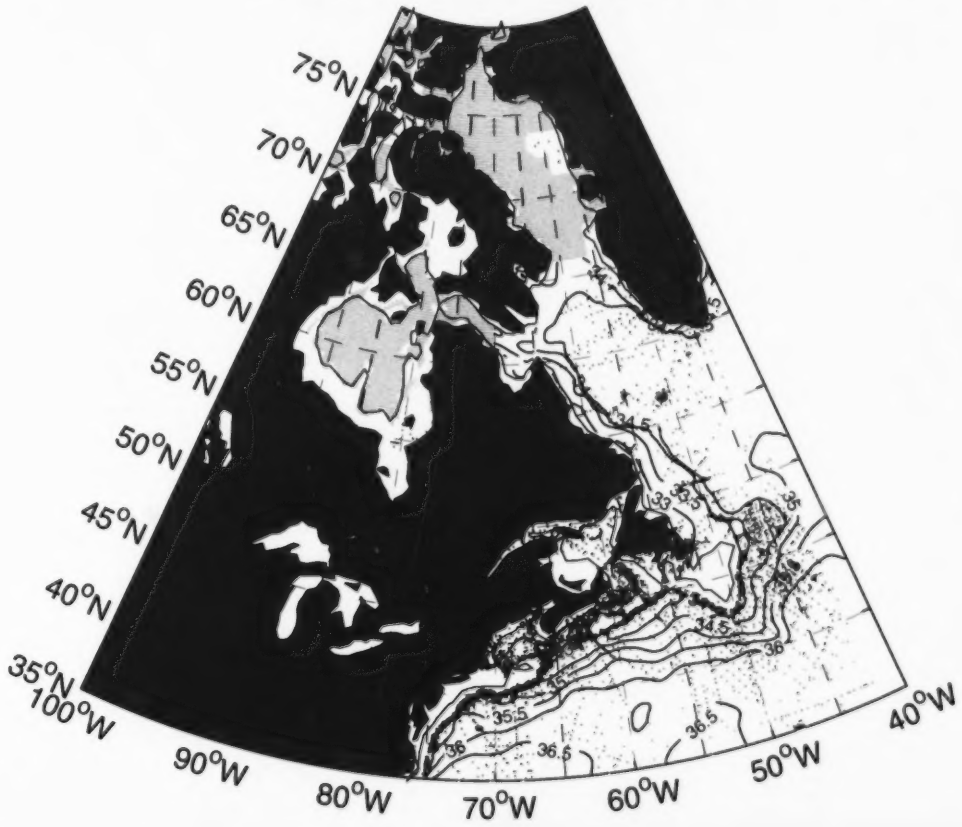
March Salinity at 0m



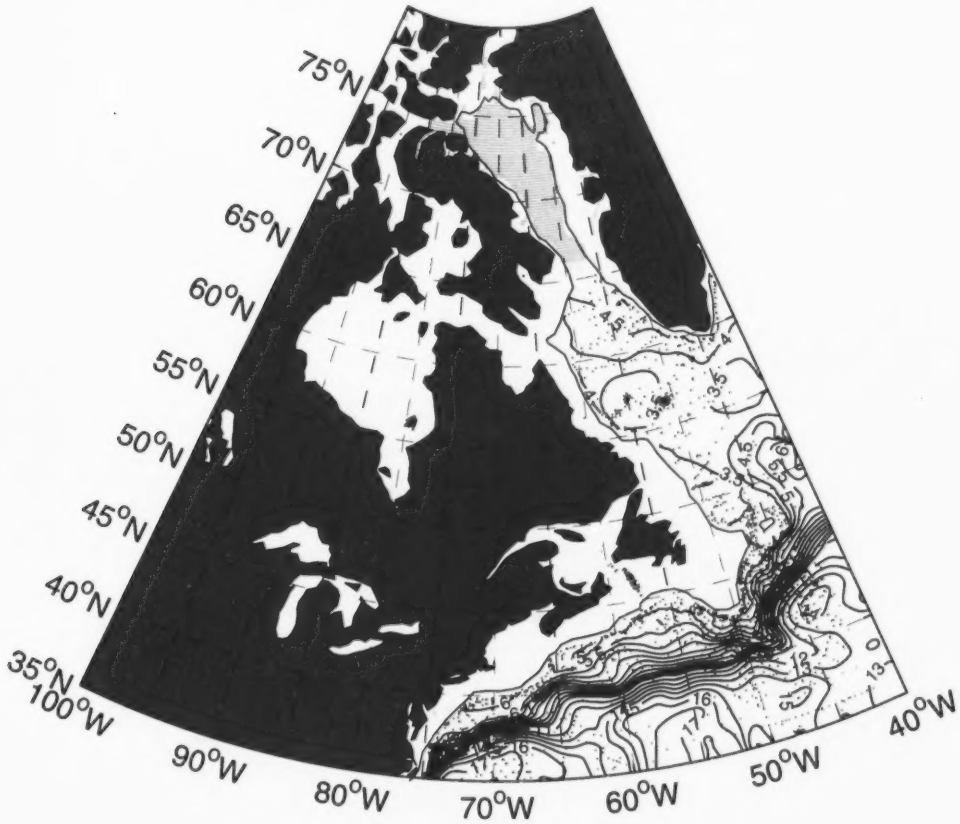
March Temperature at 100m



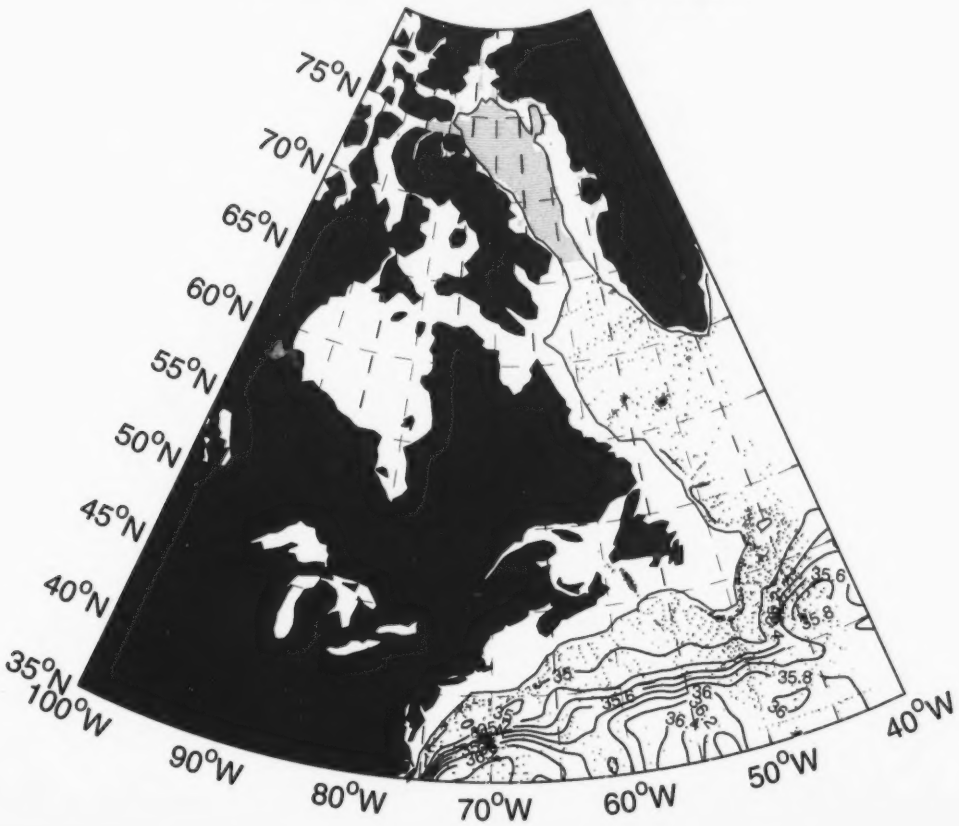
March Salinity at 100m



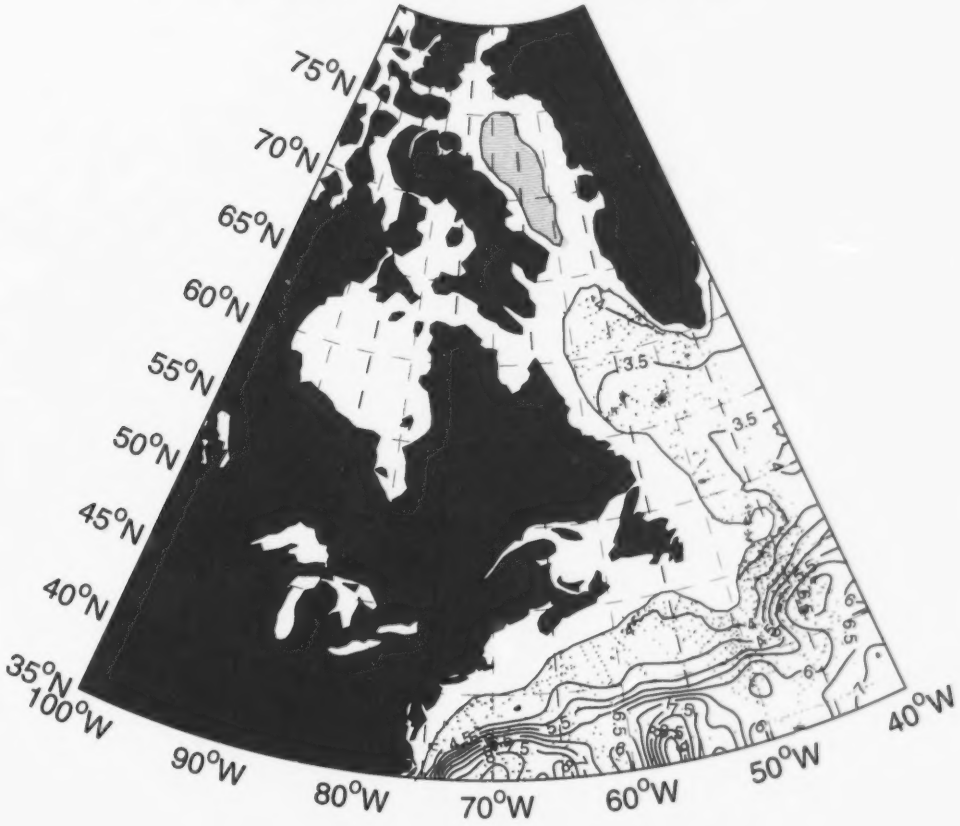
March Temperature at 500m



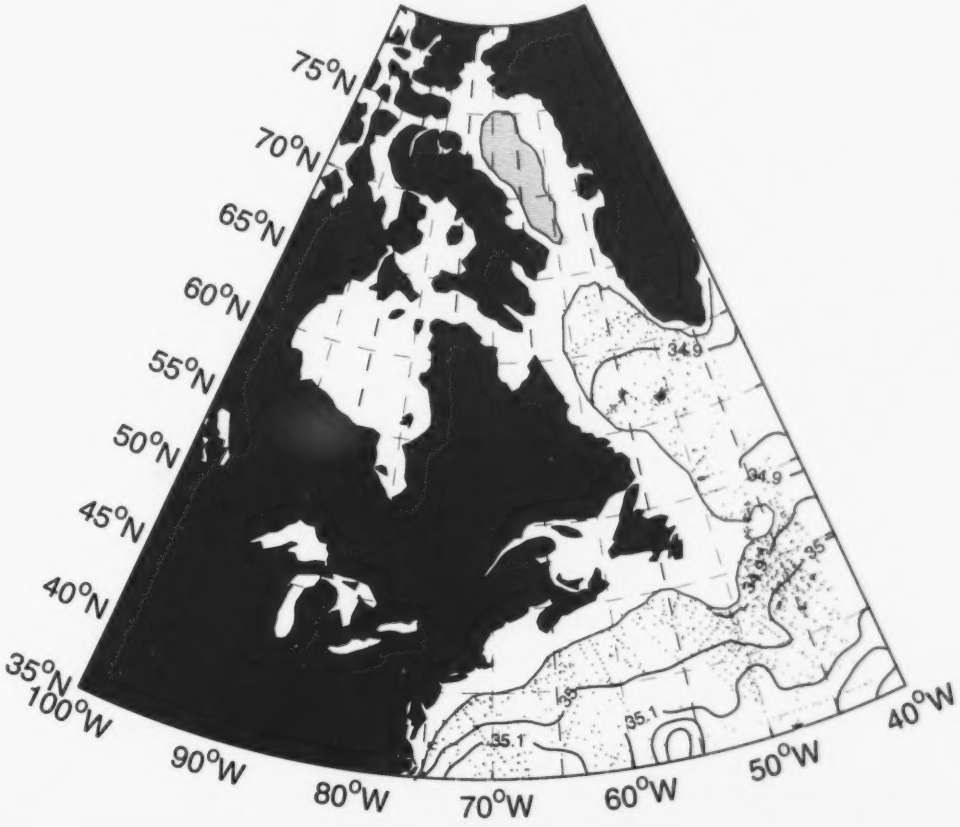
March Salinity at 500m



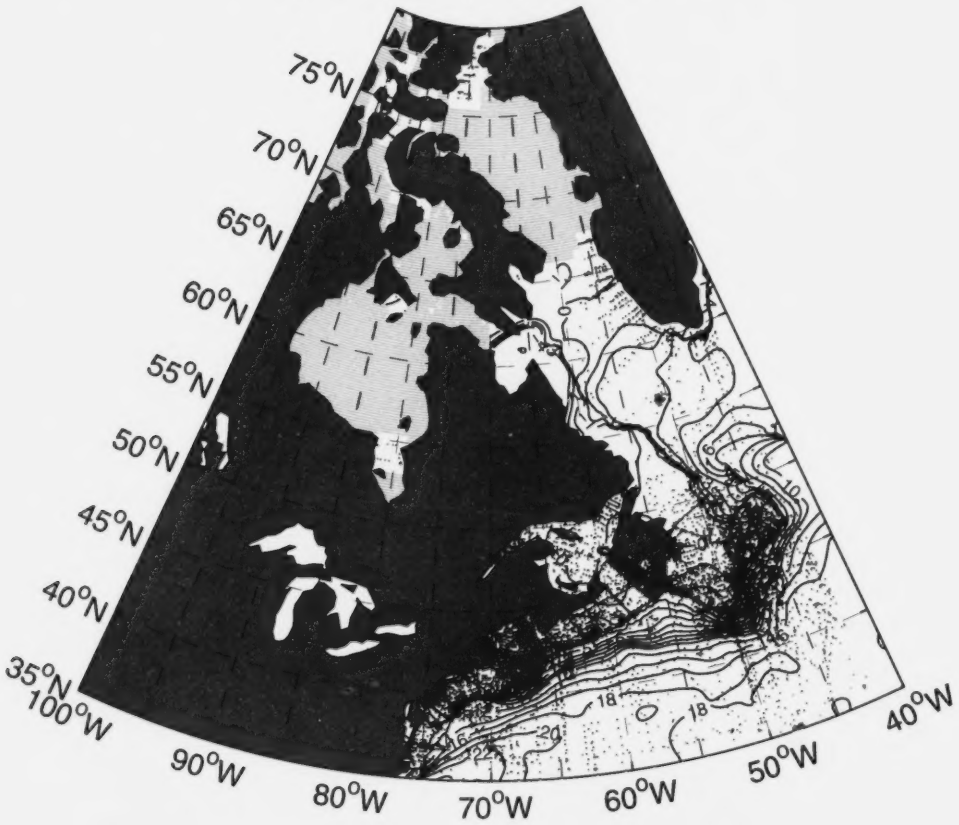
March Temperature at 1000m



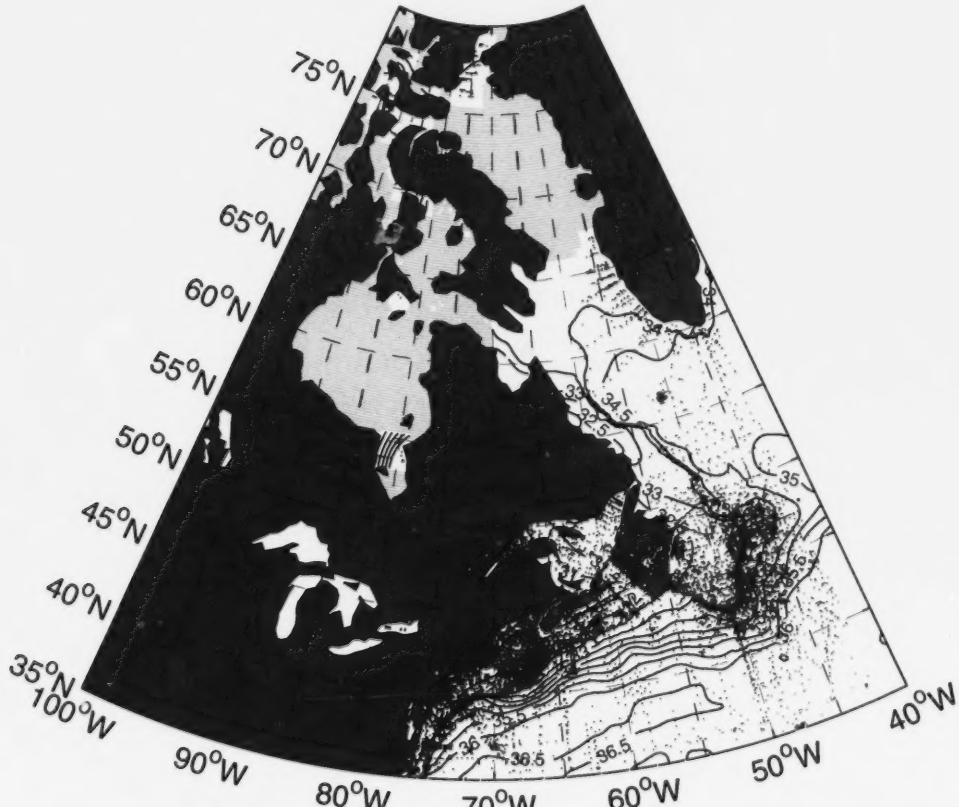
March Salinity at 1000m



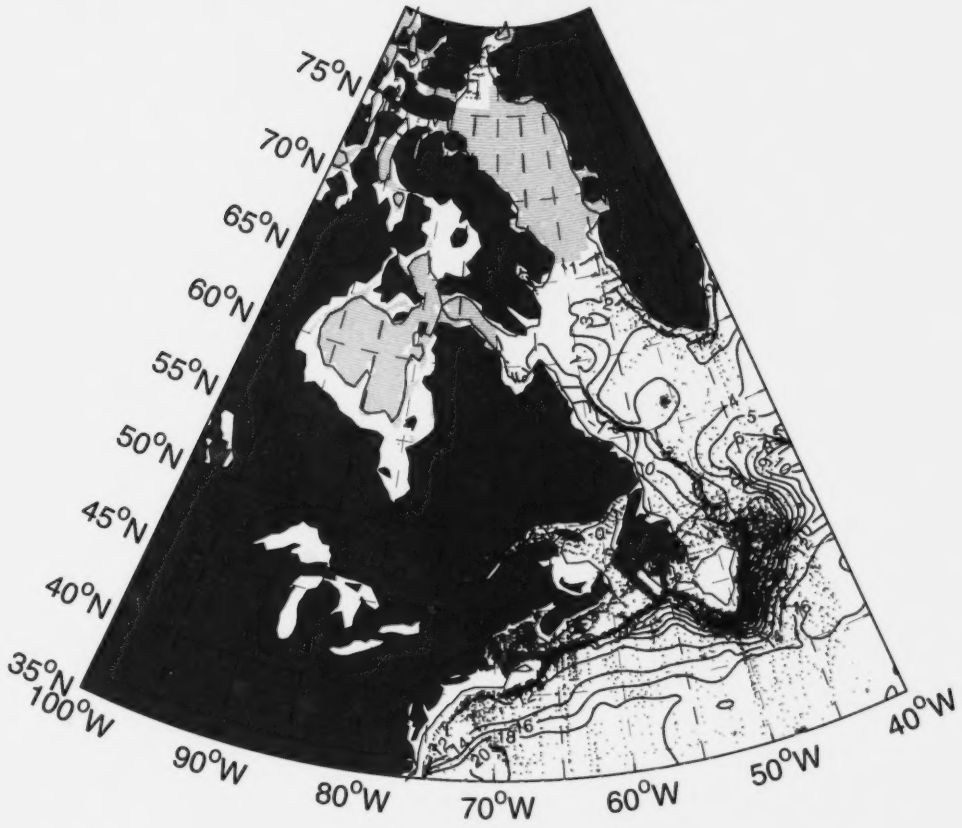
April Temperature at 0m



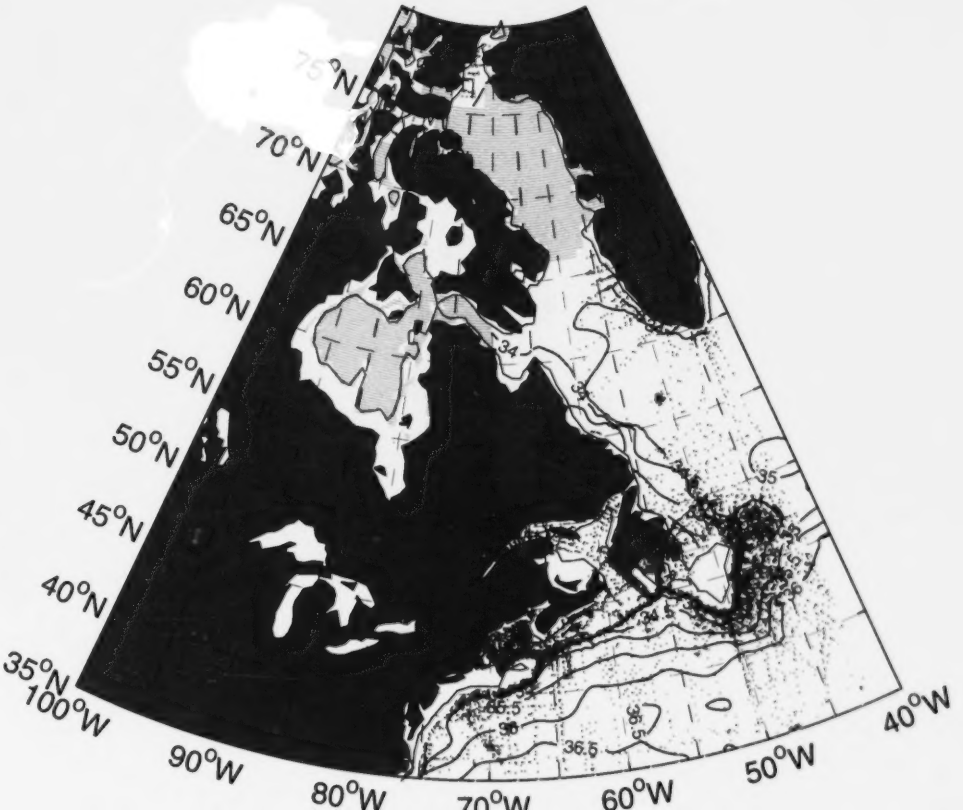
April Salinity at 0m



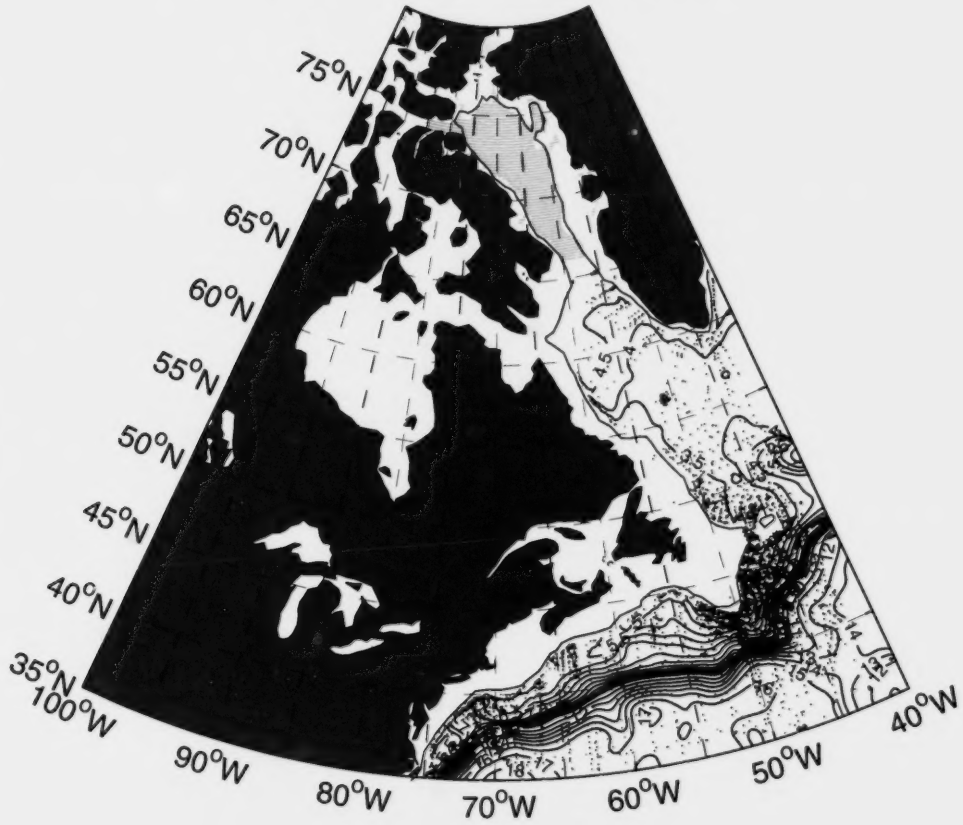
April Temperature at 100m



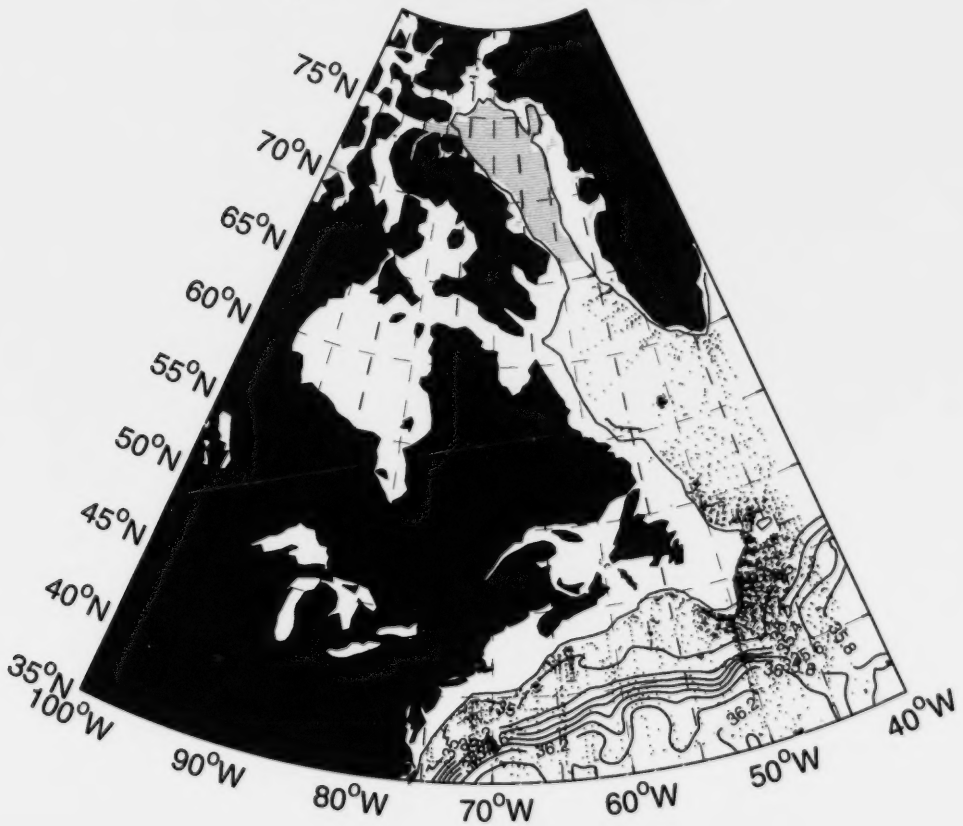
April Salinity at 100m



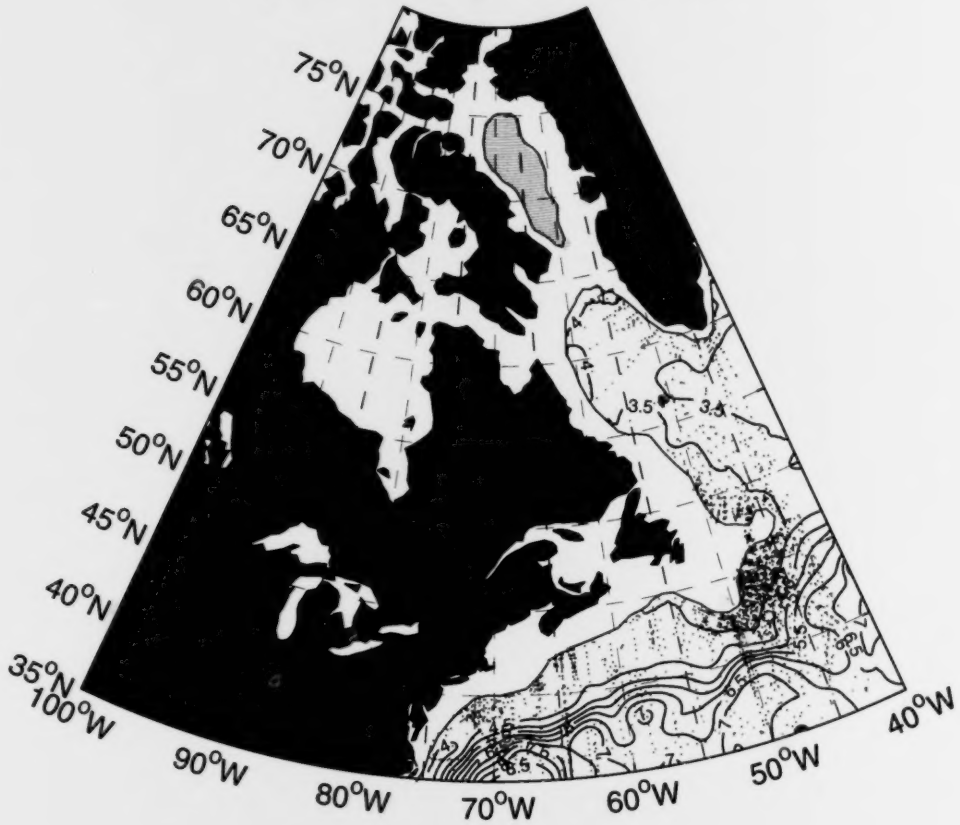
April Temperature at 500m



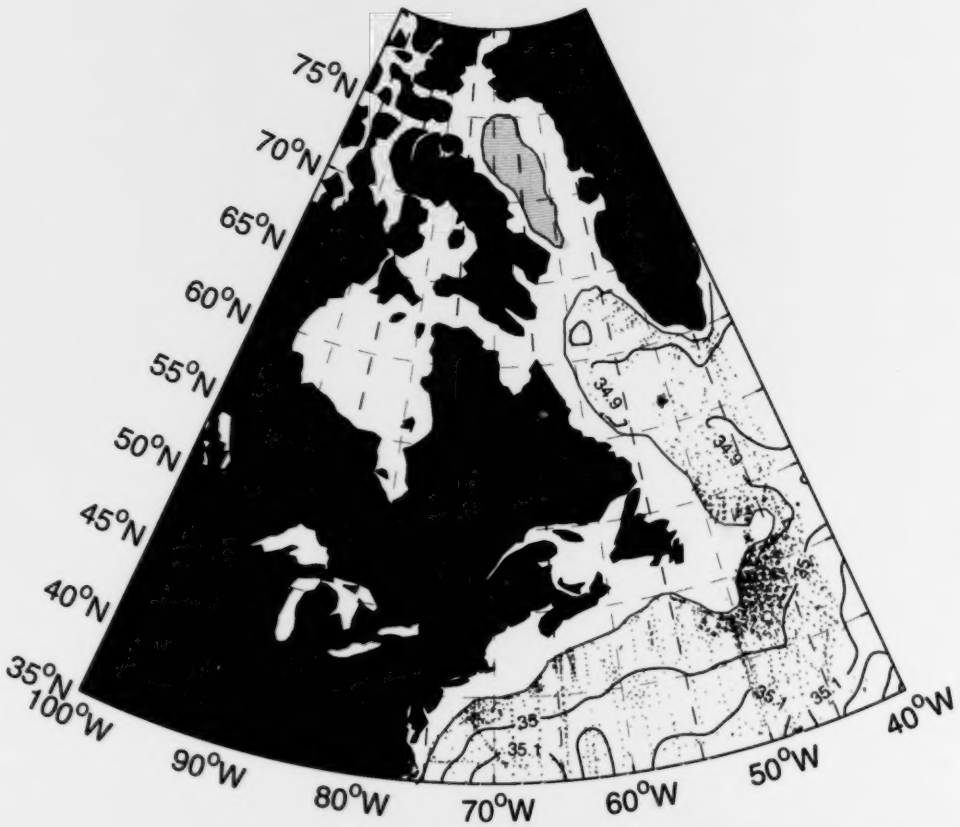
April Salinity at 500m



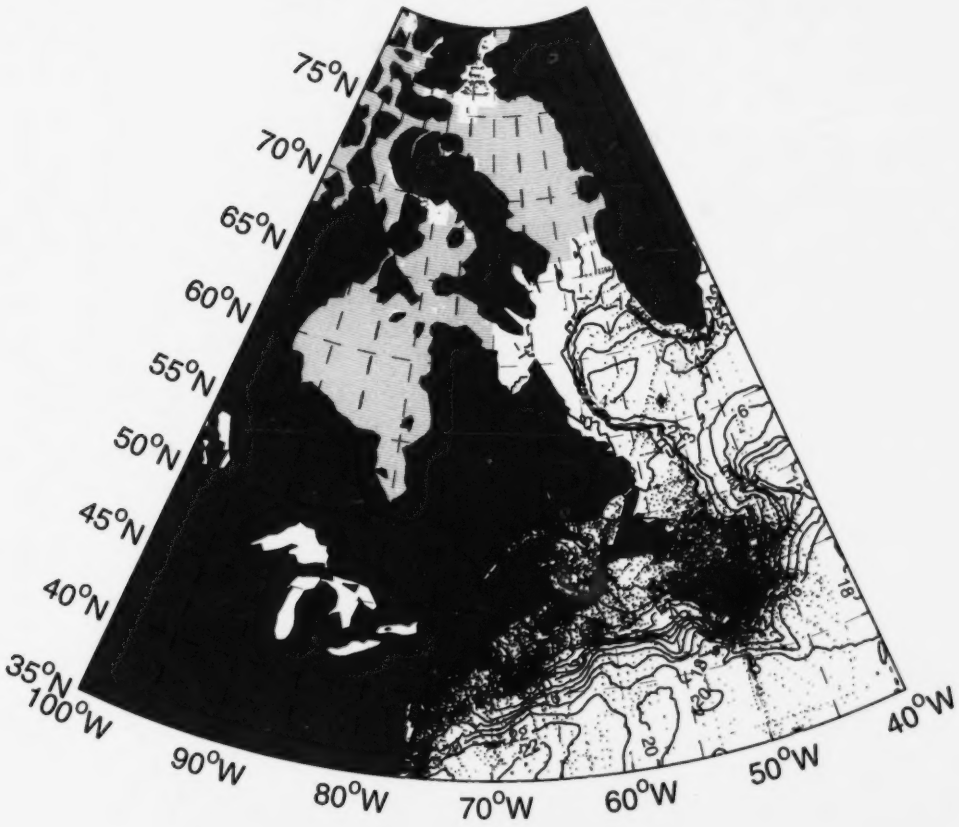
April Temperature at 1000m



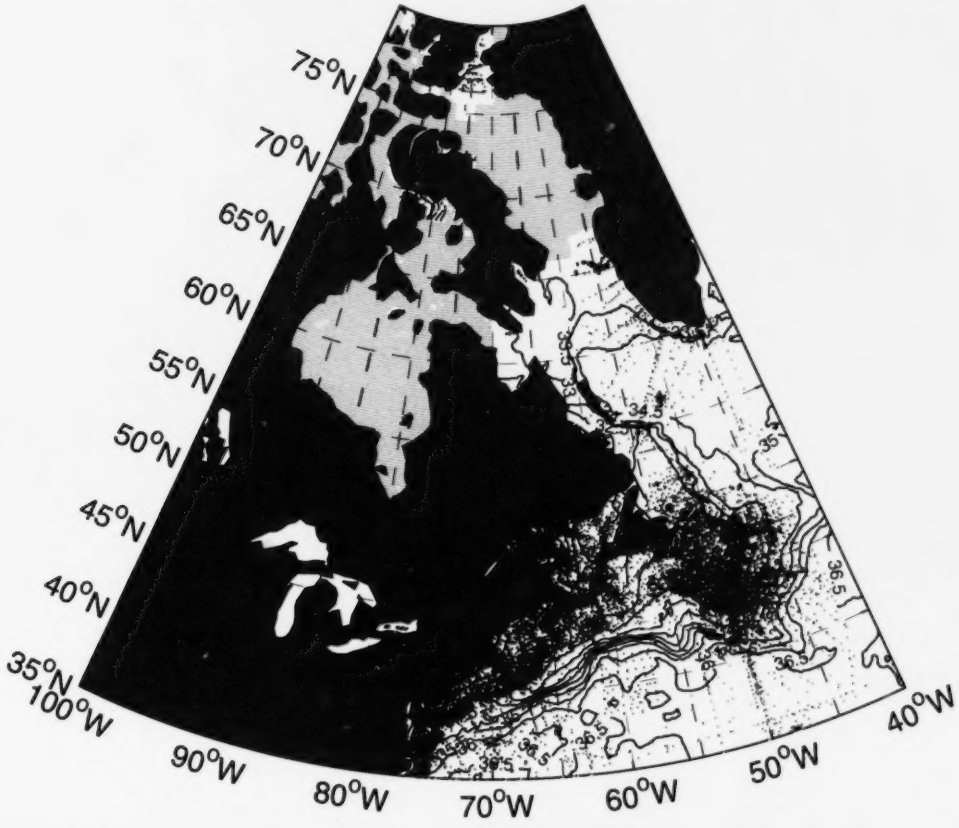
April Salinity at 1000m



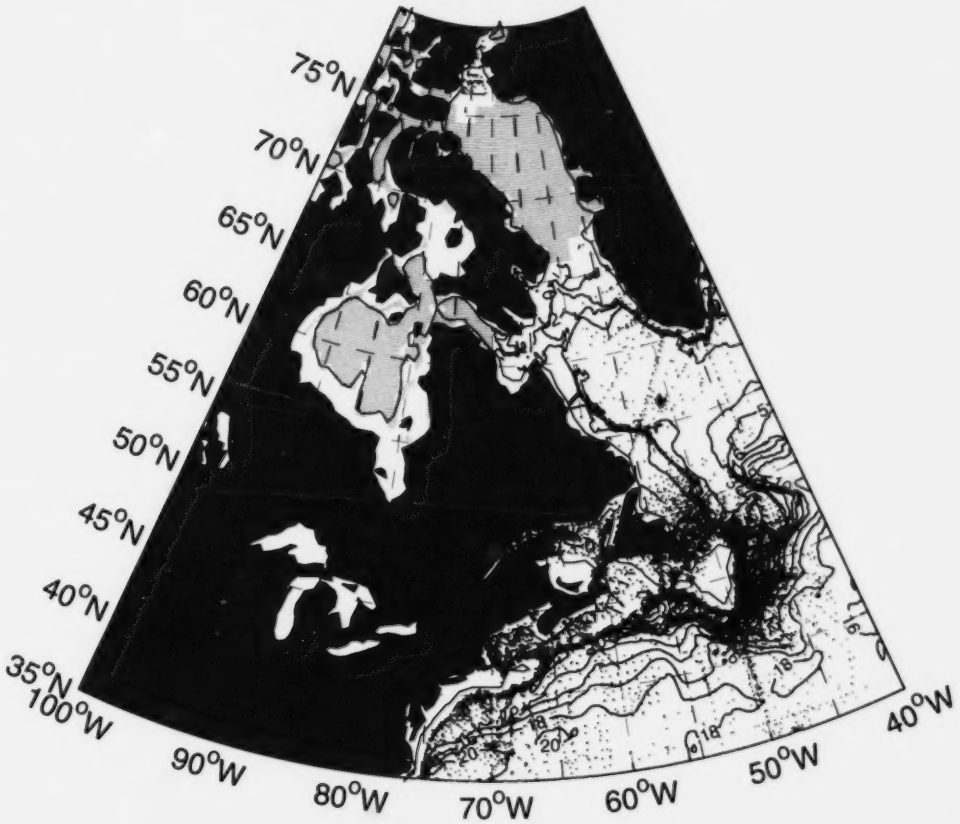
May Temperature at 0m



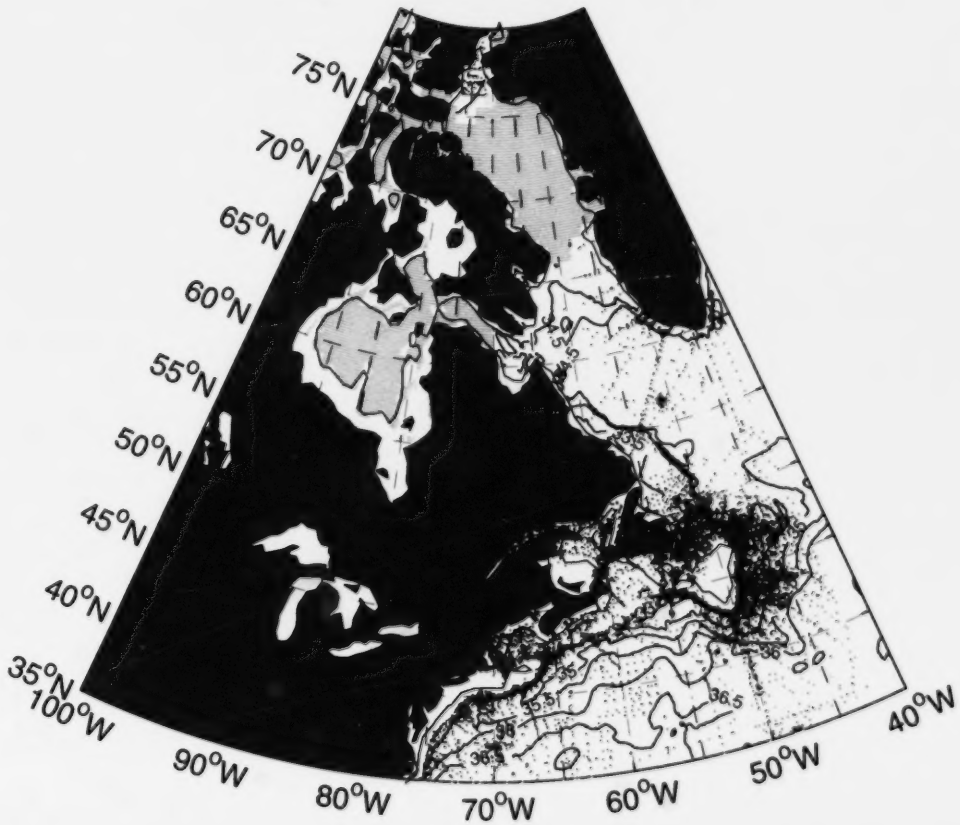
May Salinity at 0m



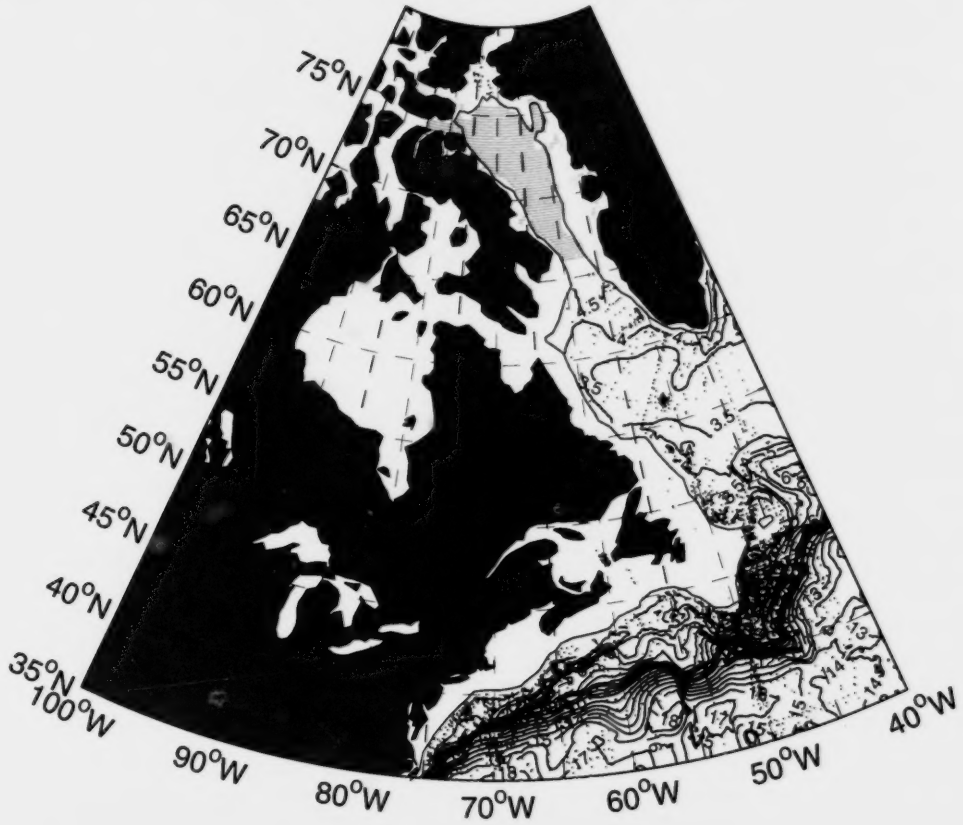
May Temperature at 100m



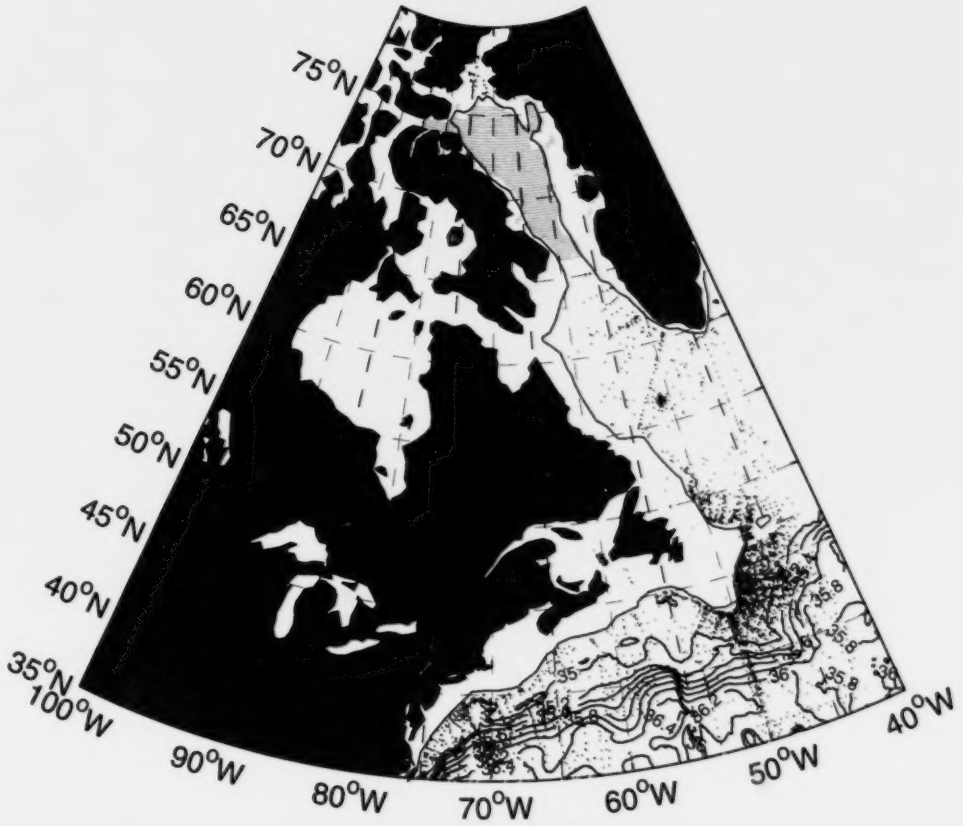
May Salinity at 100m



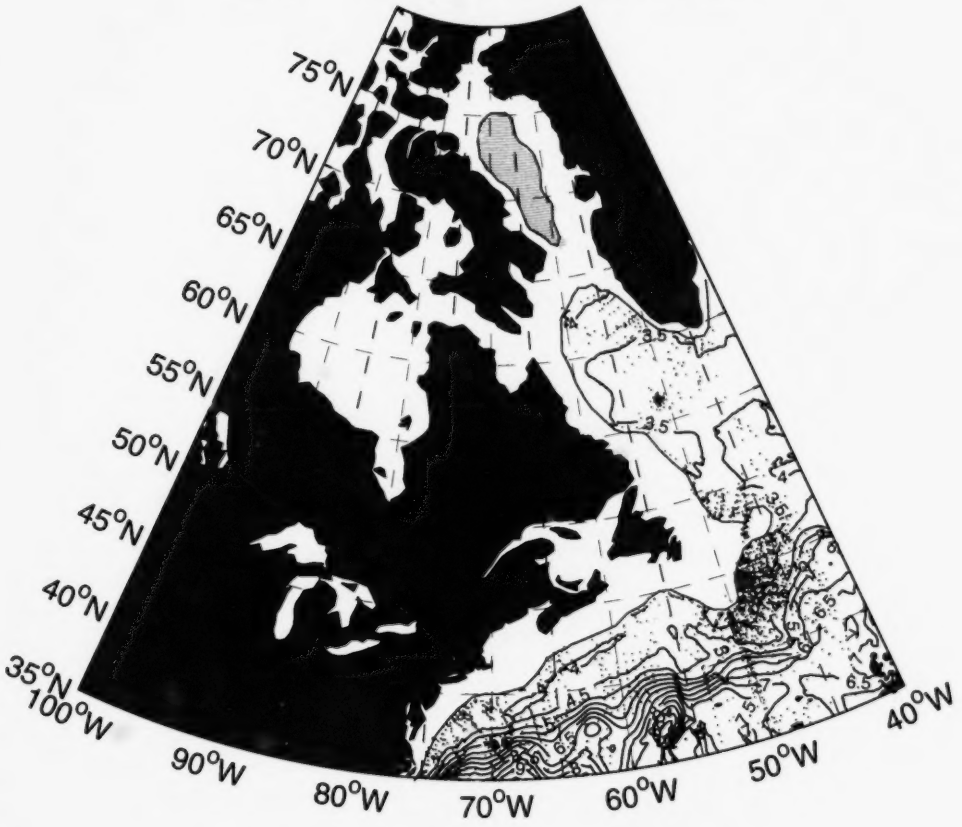
May Temperature at 500m



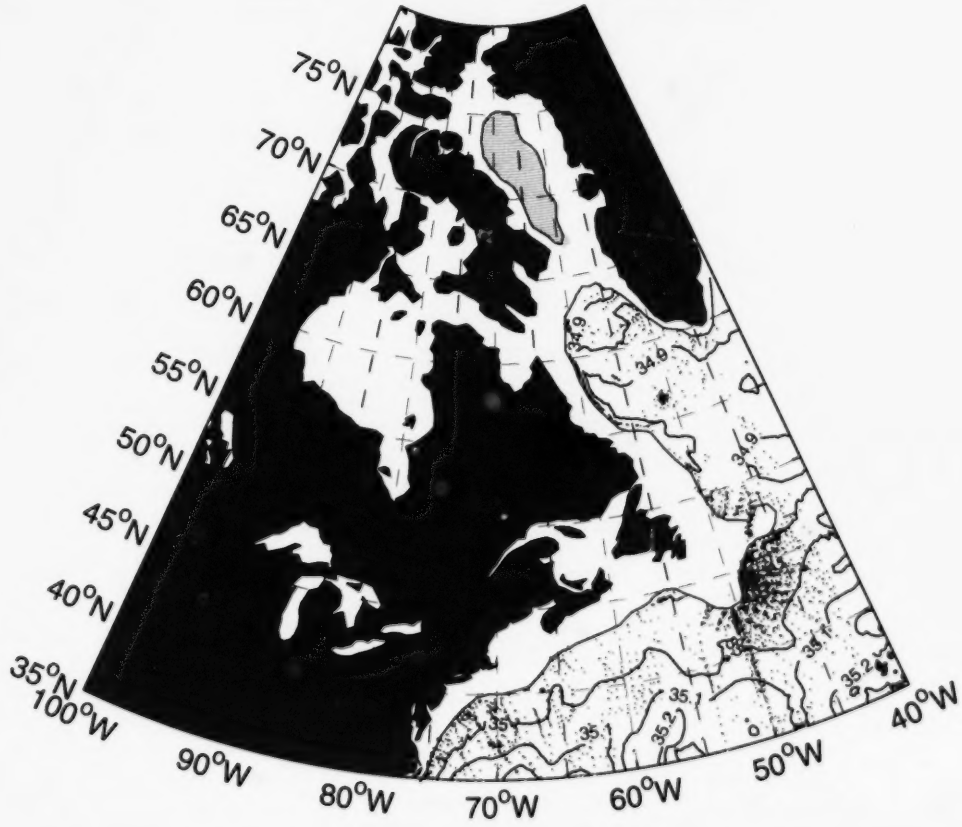
May Salinity at 500m



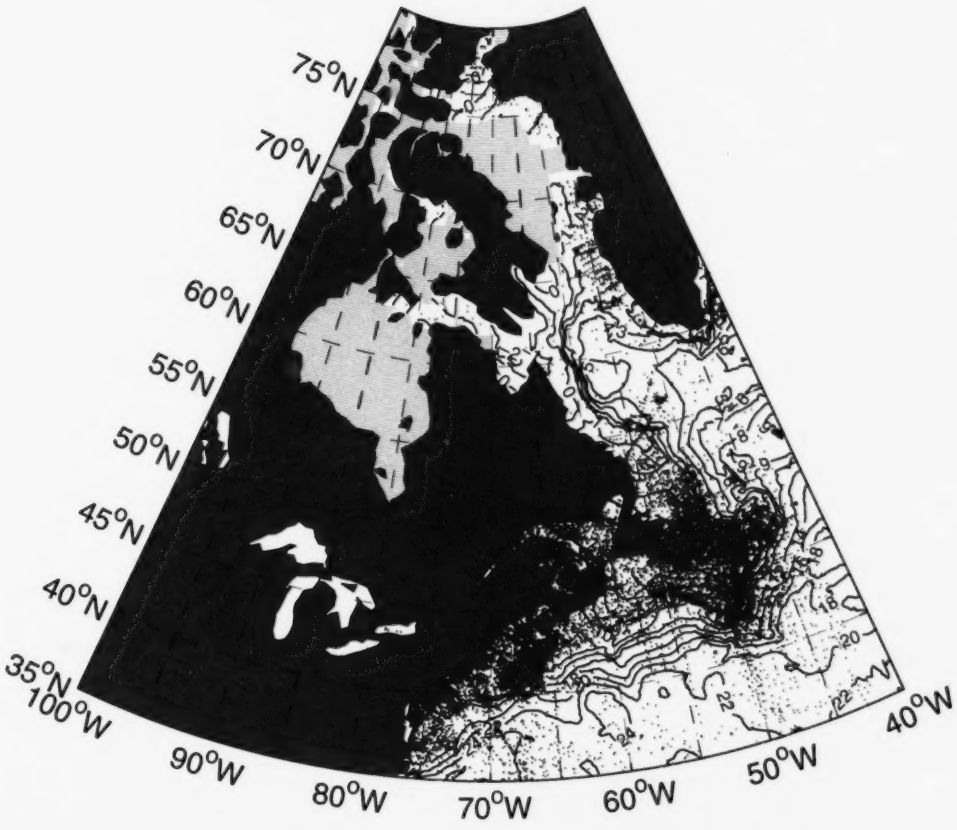
May Temperature at 1000m



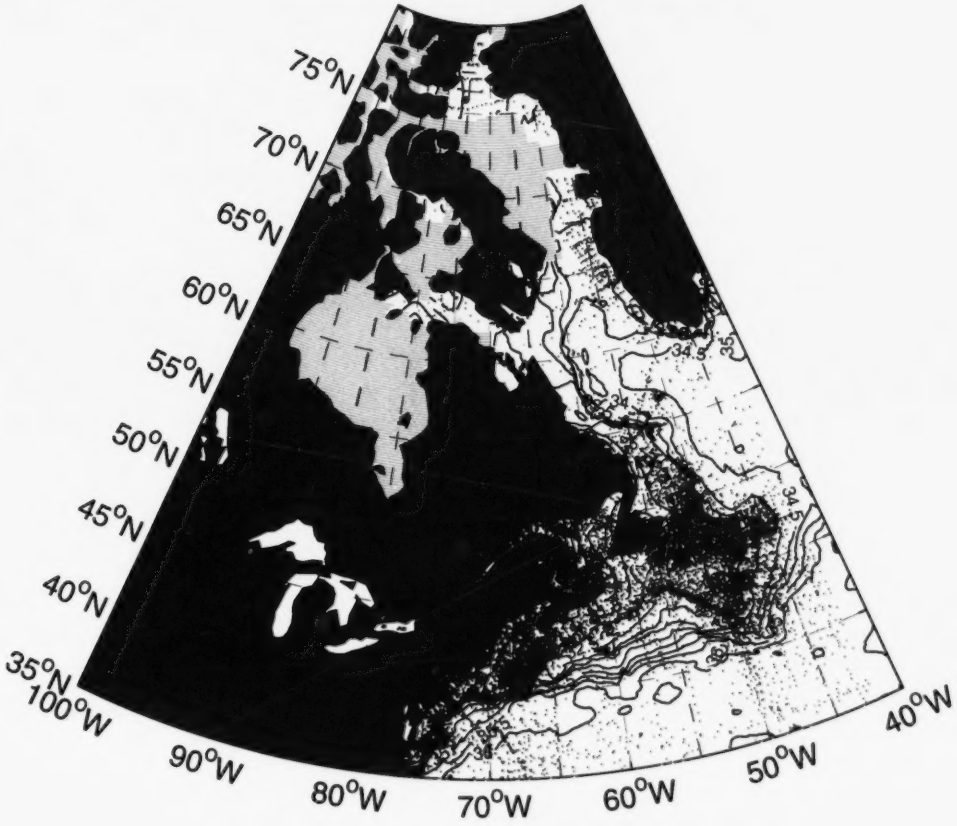
May Salinity at 1000m



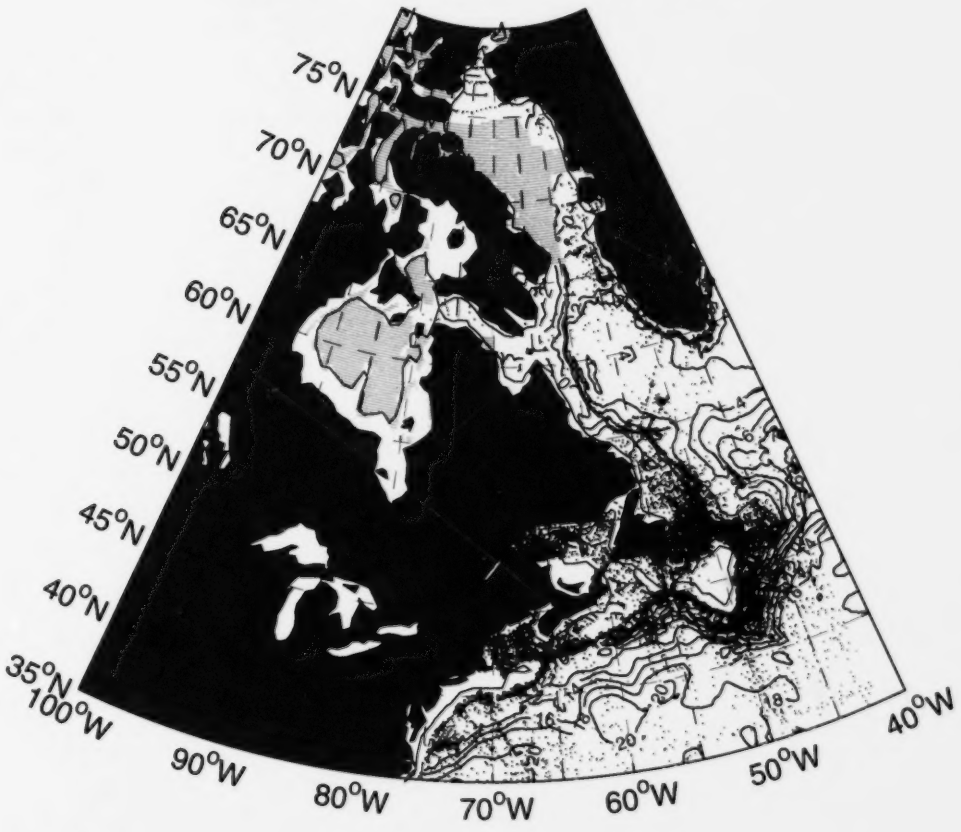
June Temperature at 0m



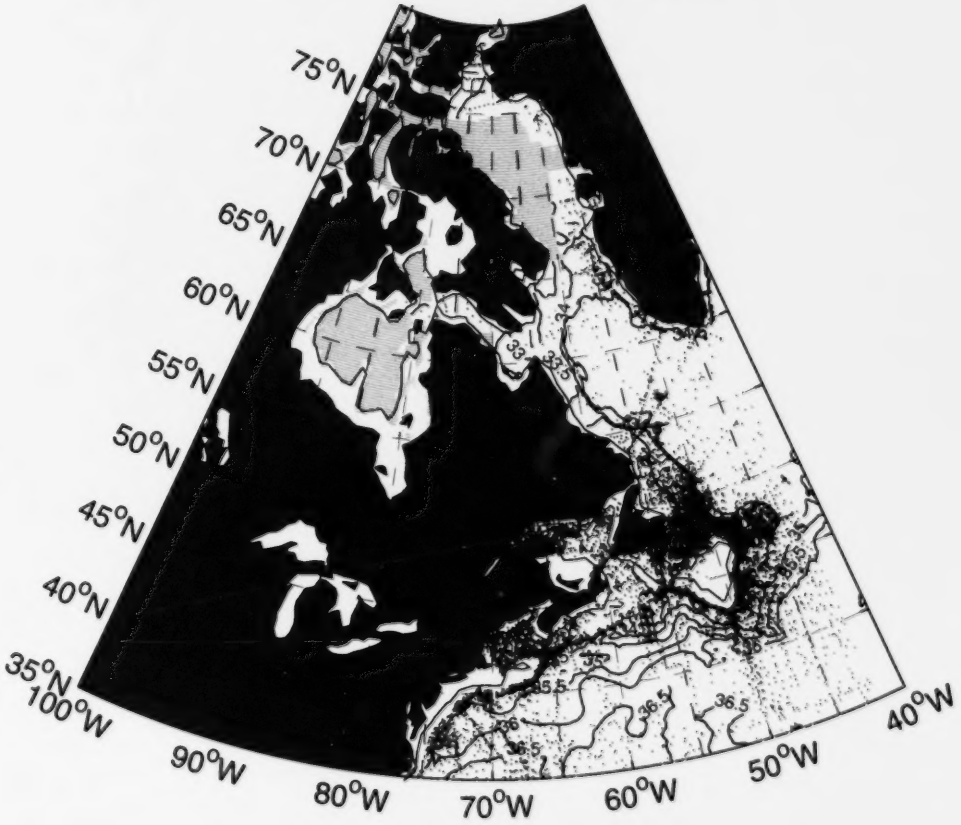
June Salinity at 0m



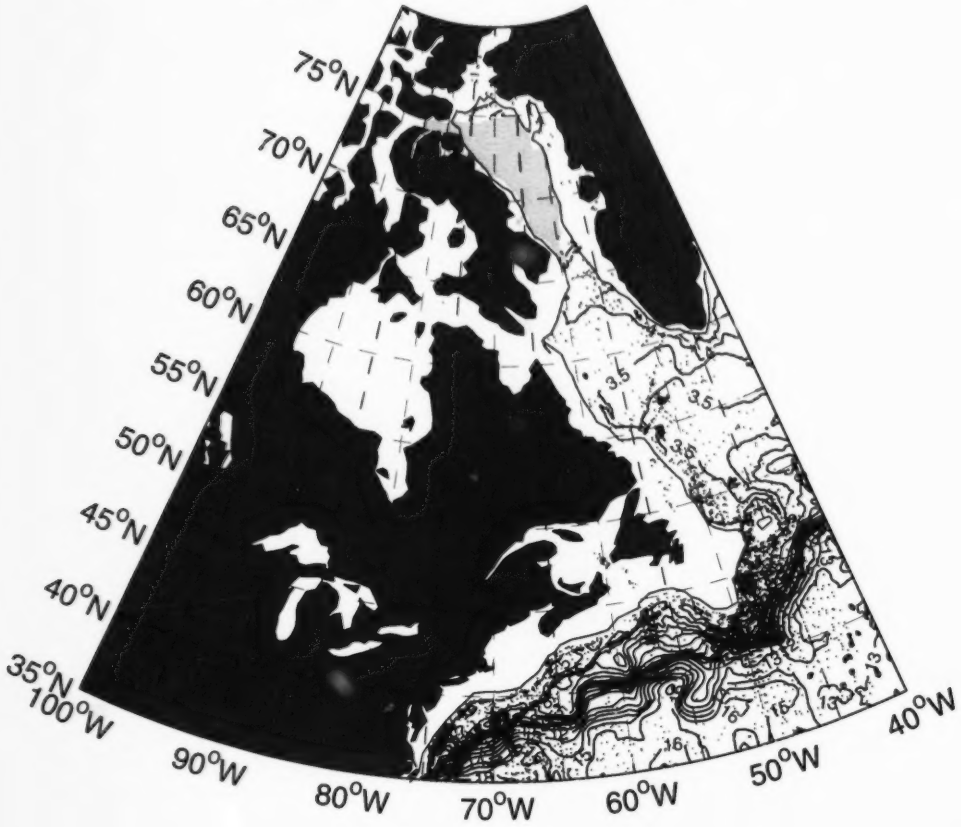
June Temperature at 100m



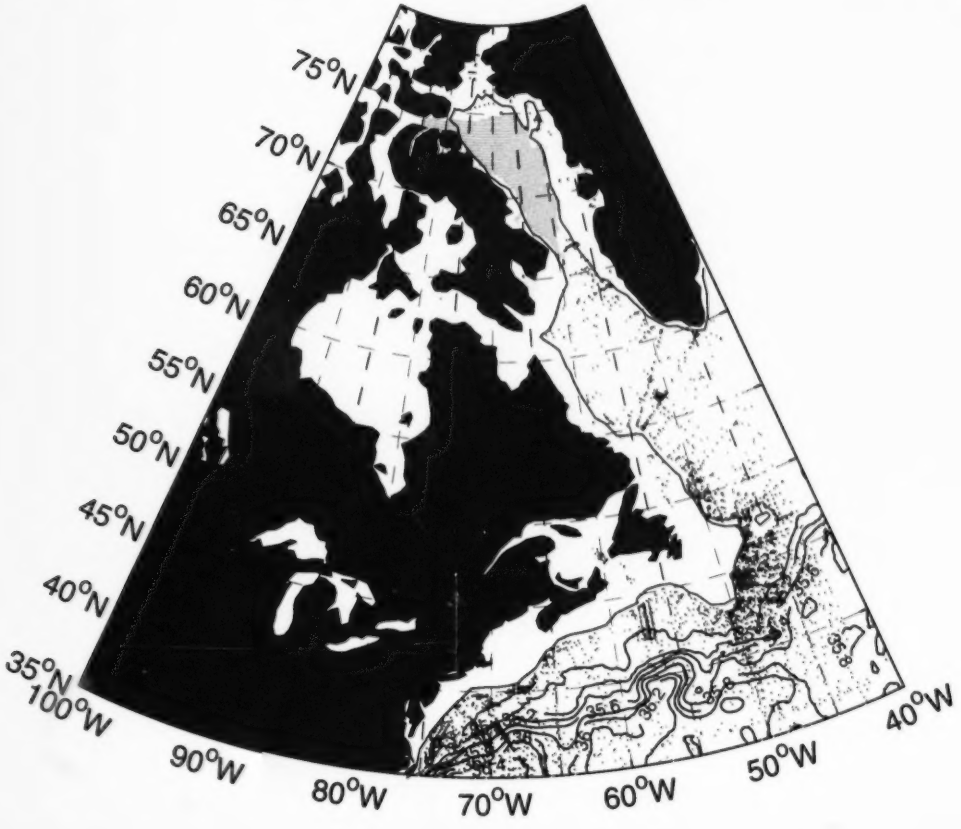
June Salinity at 100m



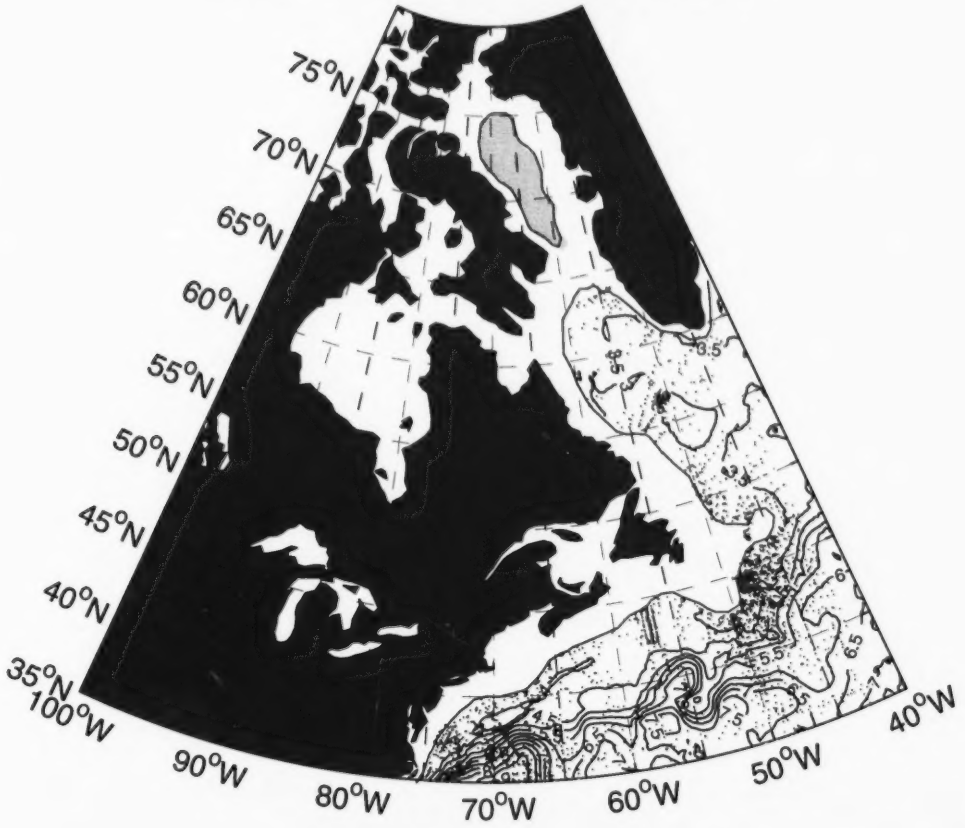
June Temperature at 500m



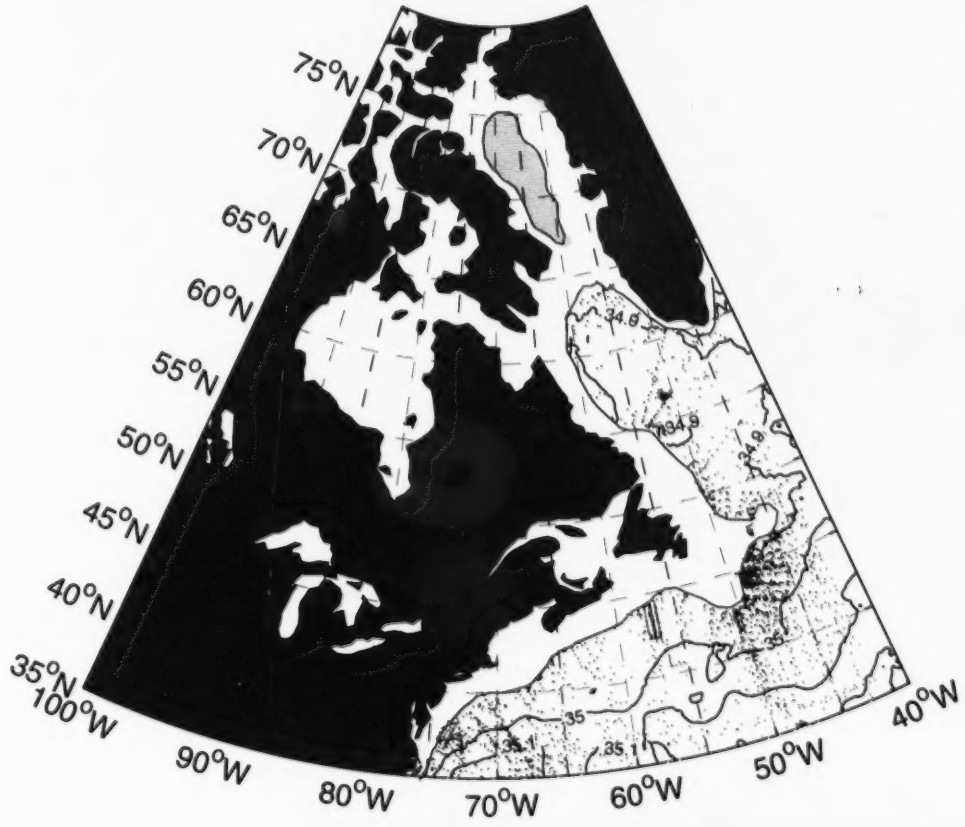
June Salinity at 500m



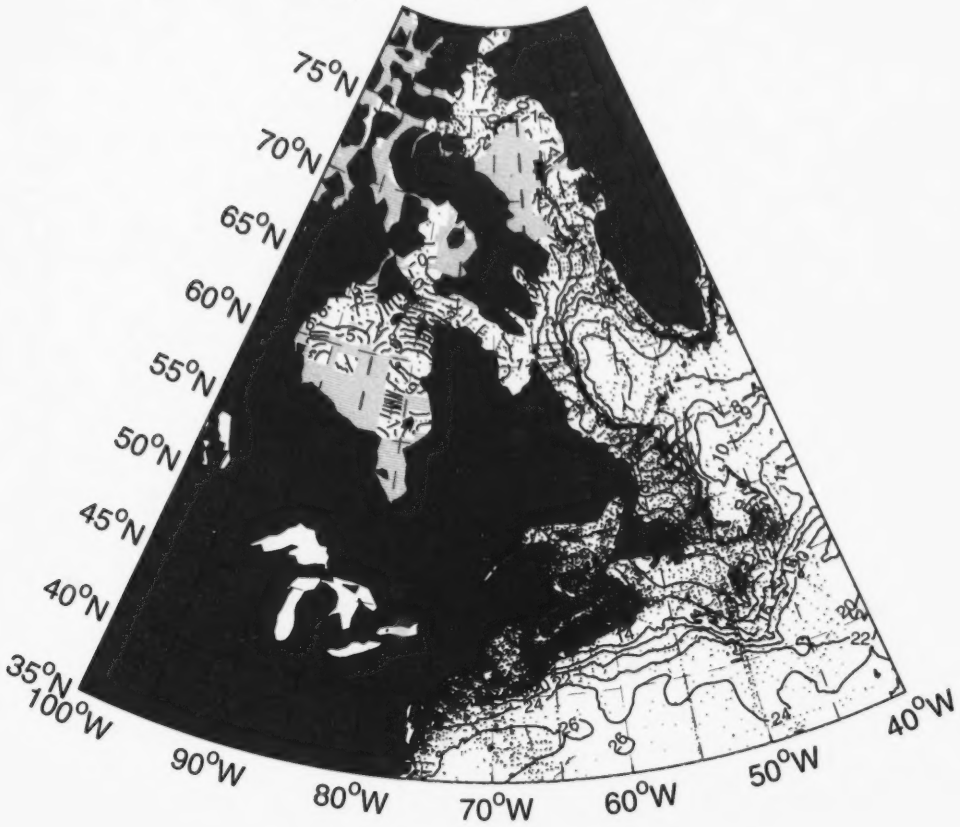
June Temperature at 1000m



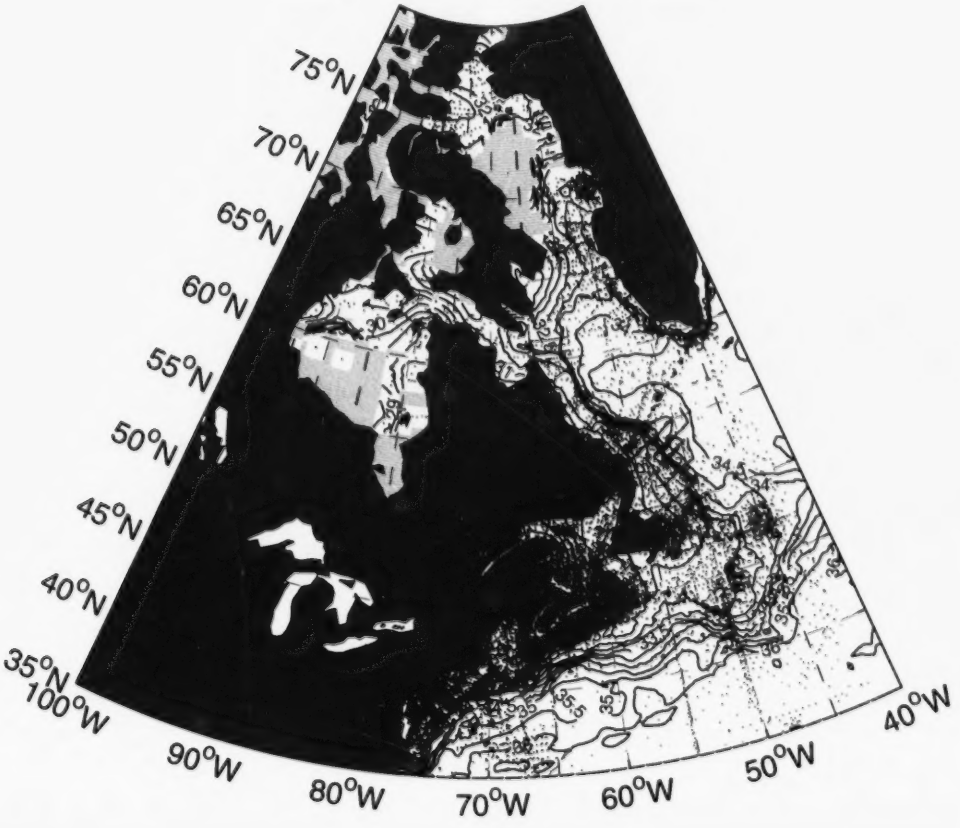
June Salinity at 1000m



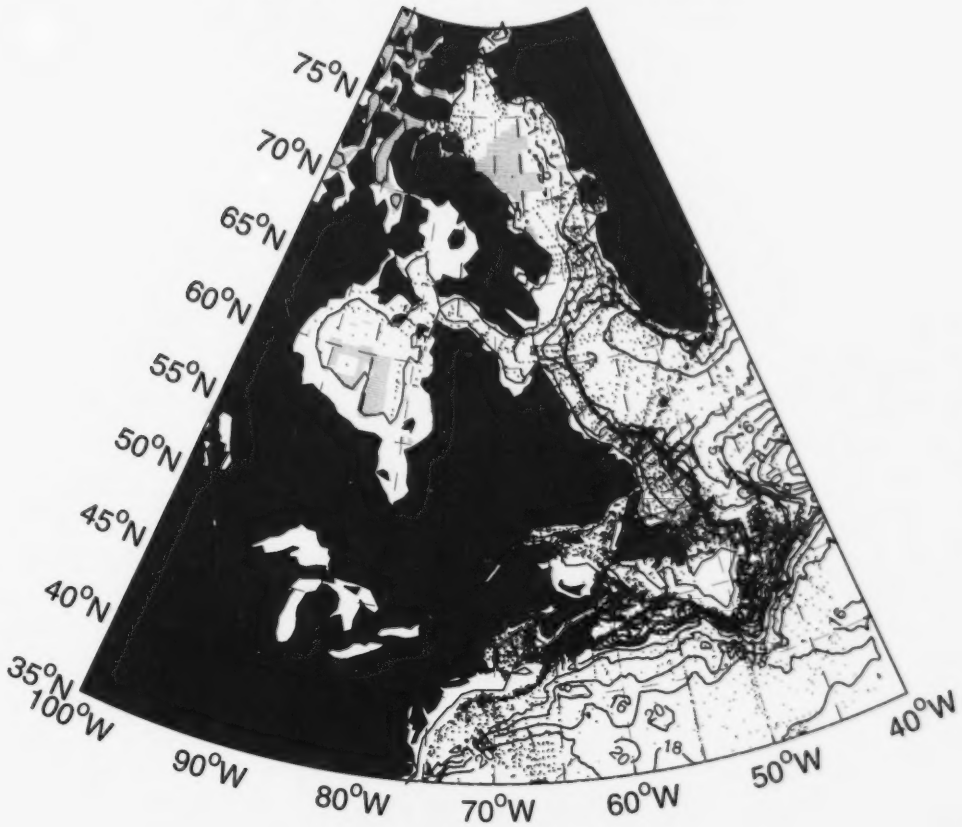
July Temperature at 0m



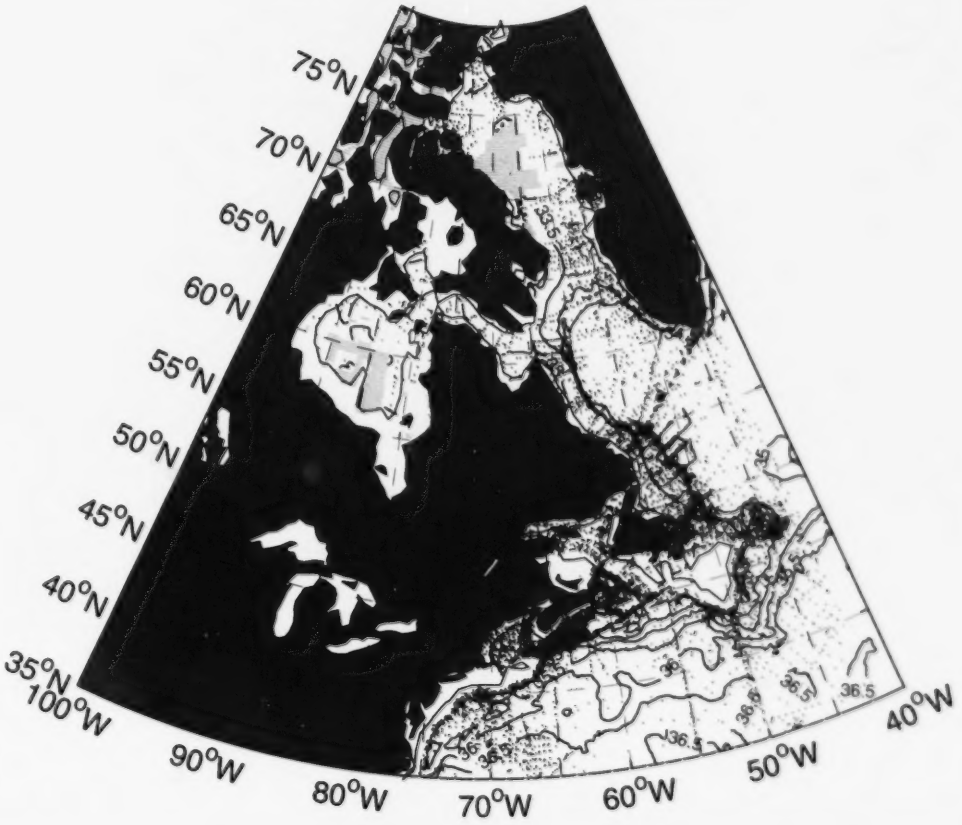
July Salinity at 0m



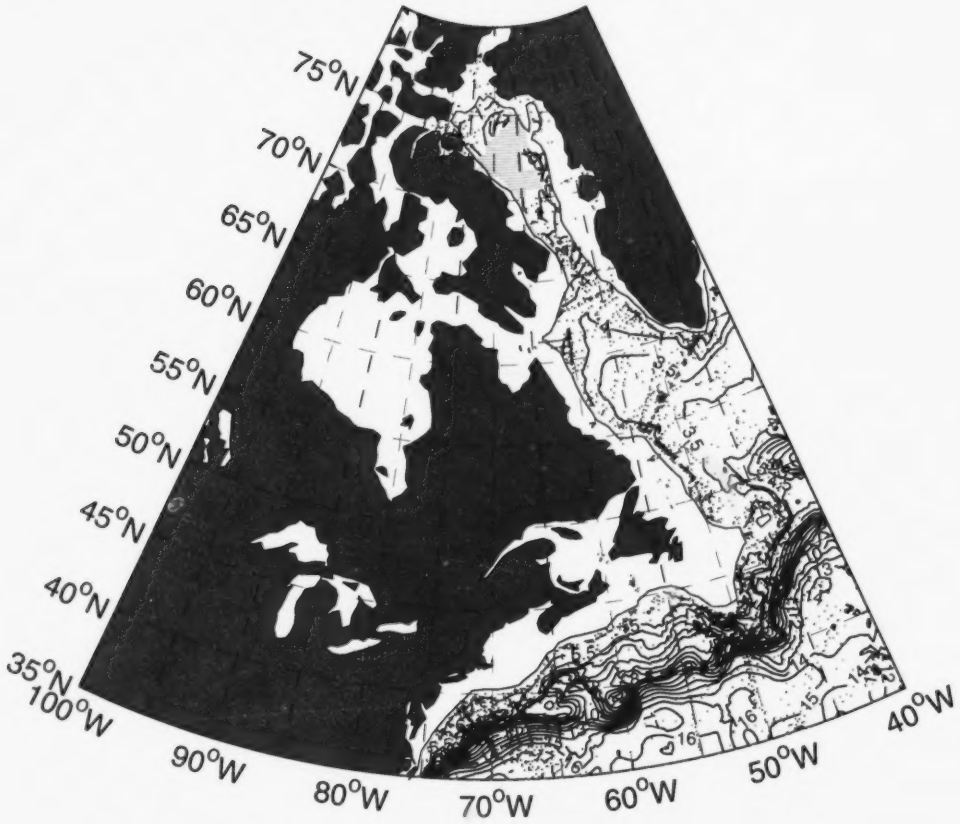
July Temperature at 100m



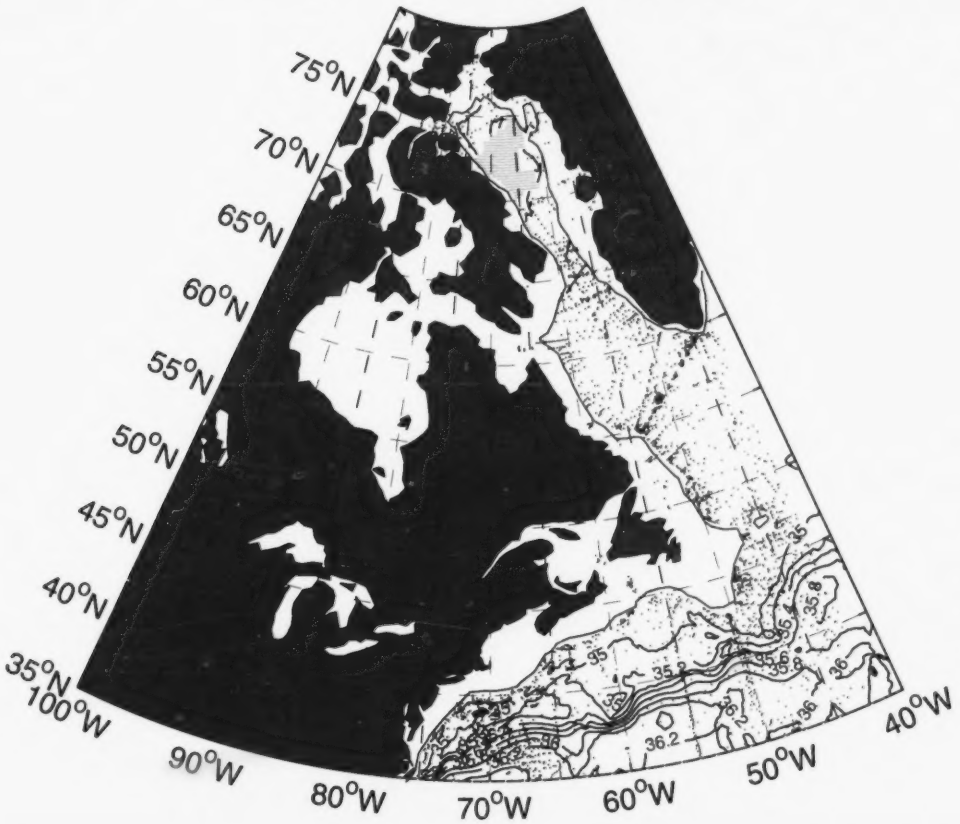
July Salinity at 100m



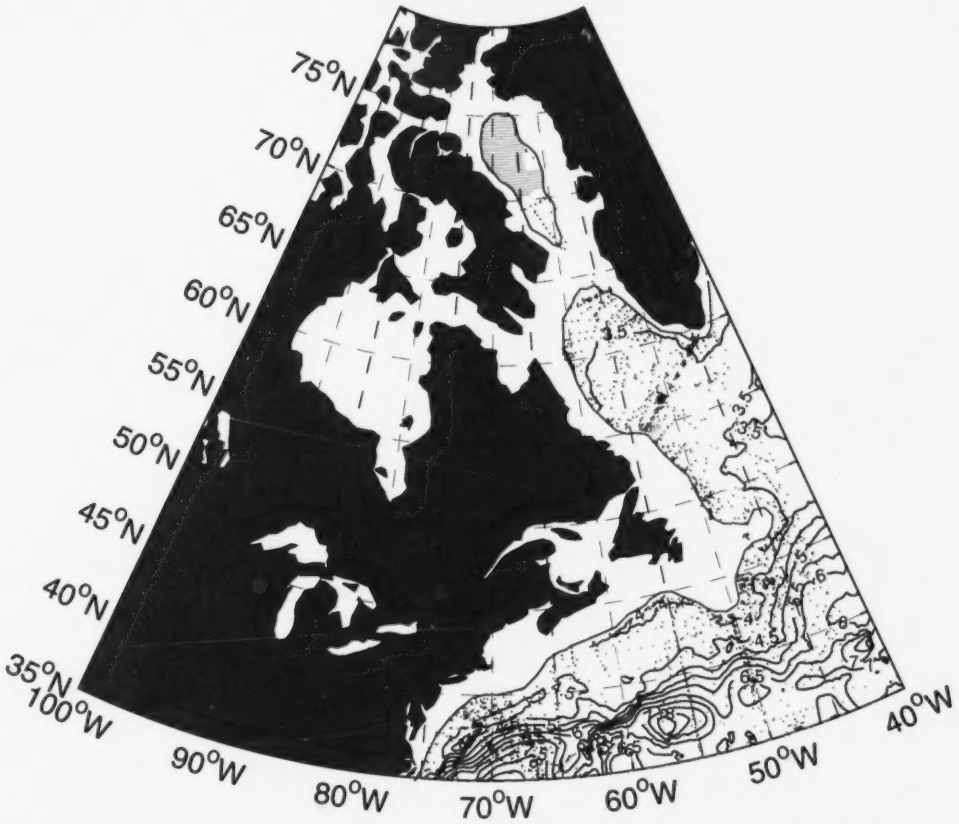
July Temperature at 500m



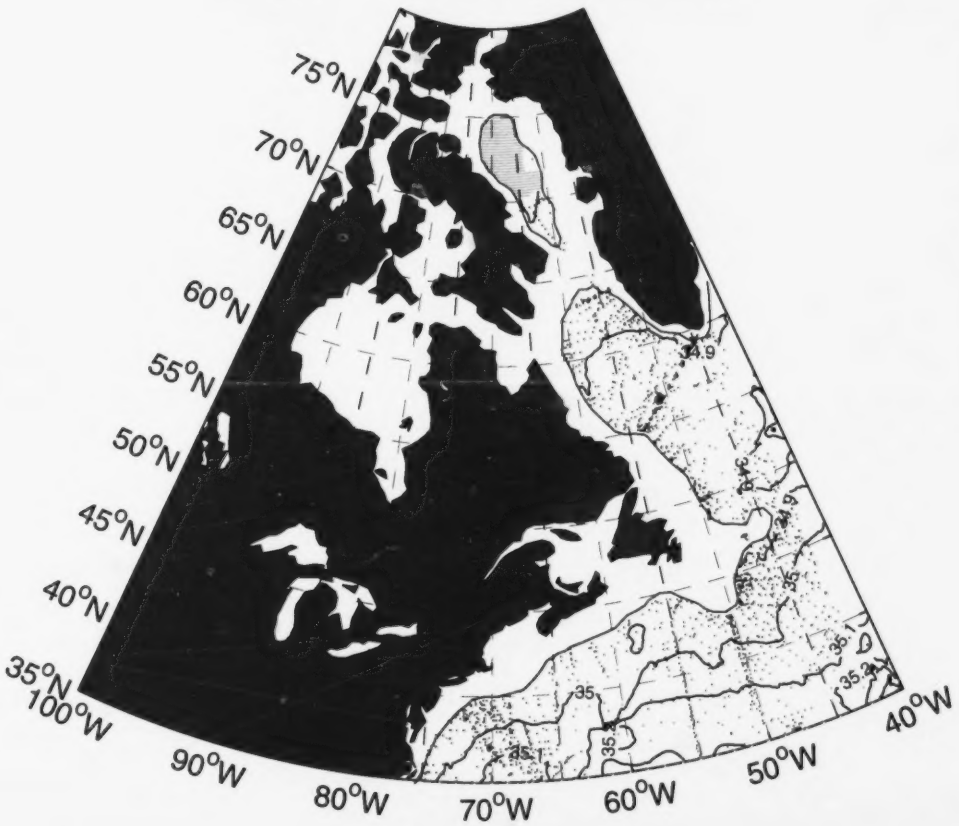
July Salinity at 500m



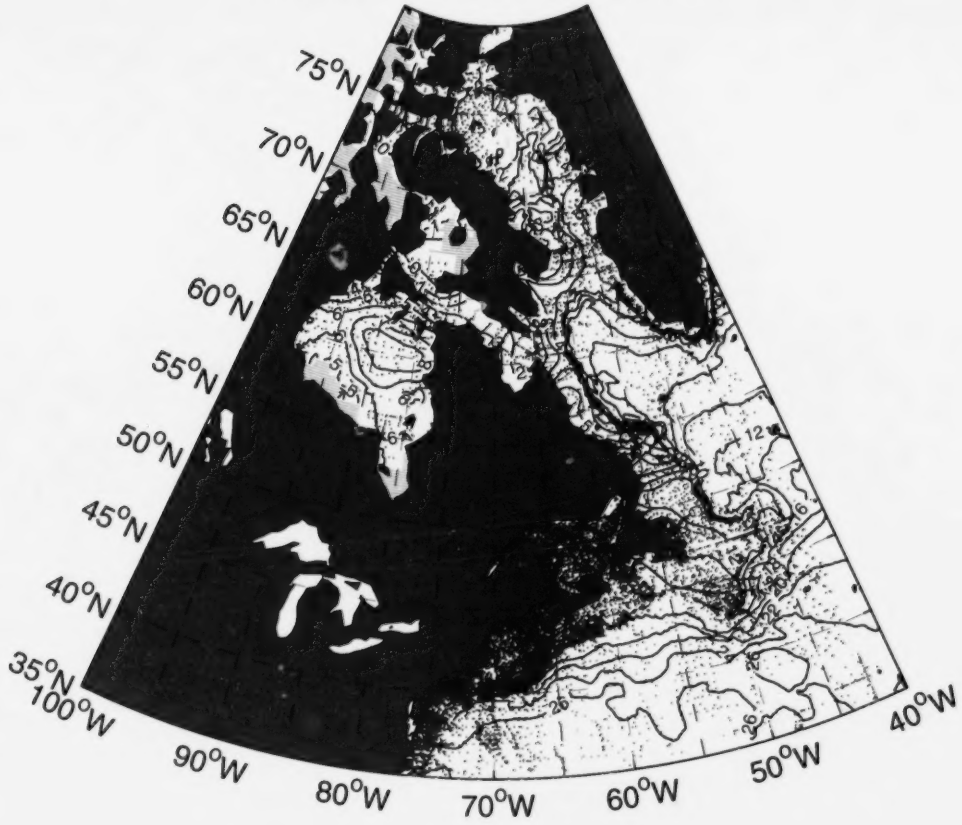
July Temperature at 1000m



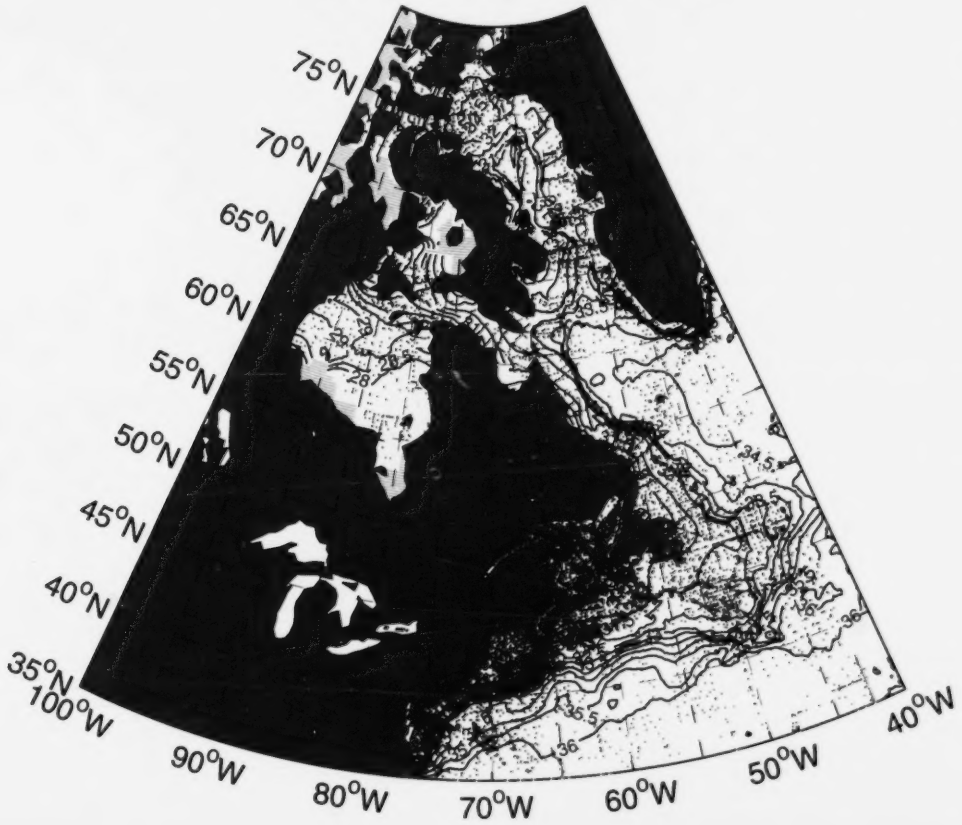
July Salinity at 1000m



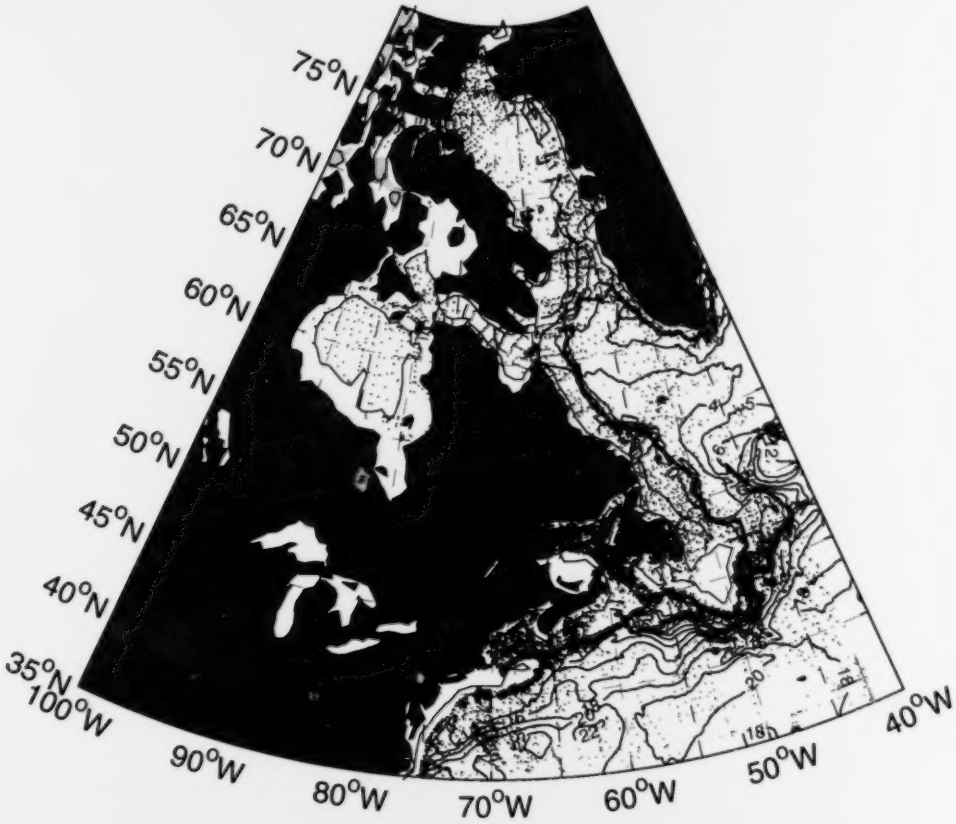
August Temperature at 0m



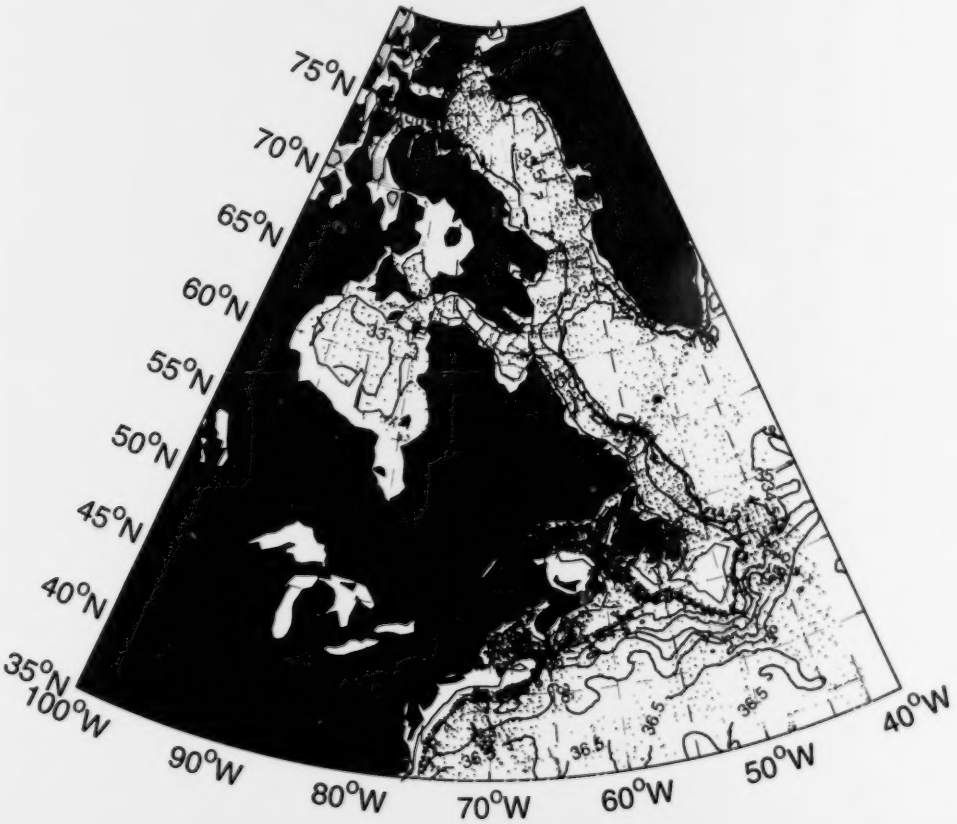
August Salinity at 0m



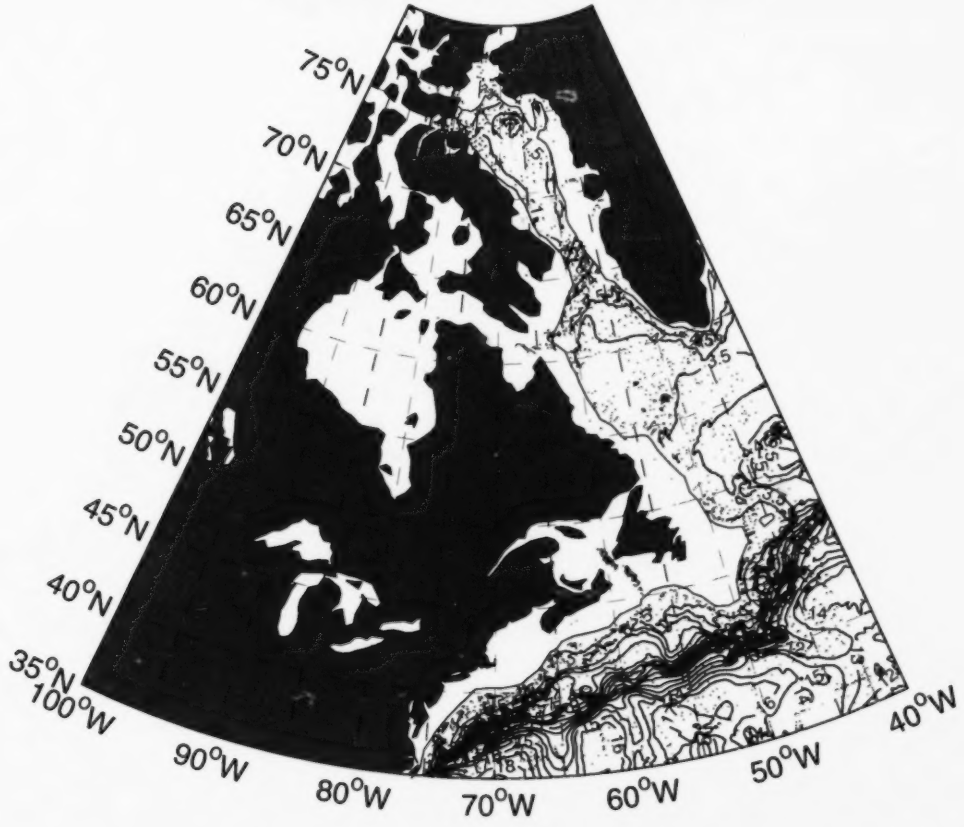
August Temperature at 100m



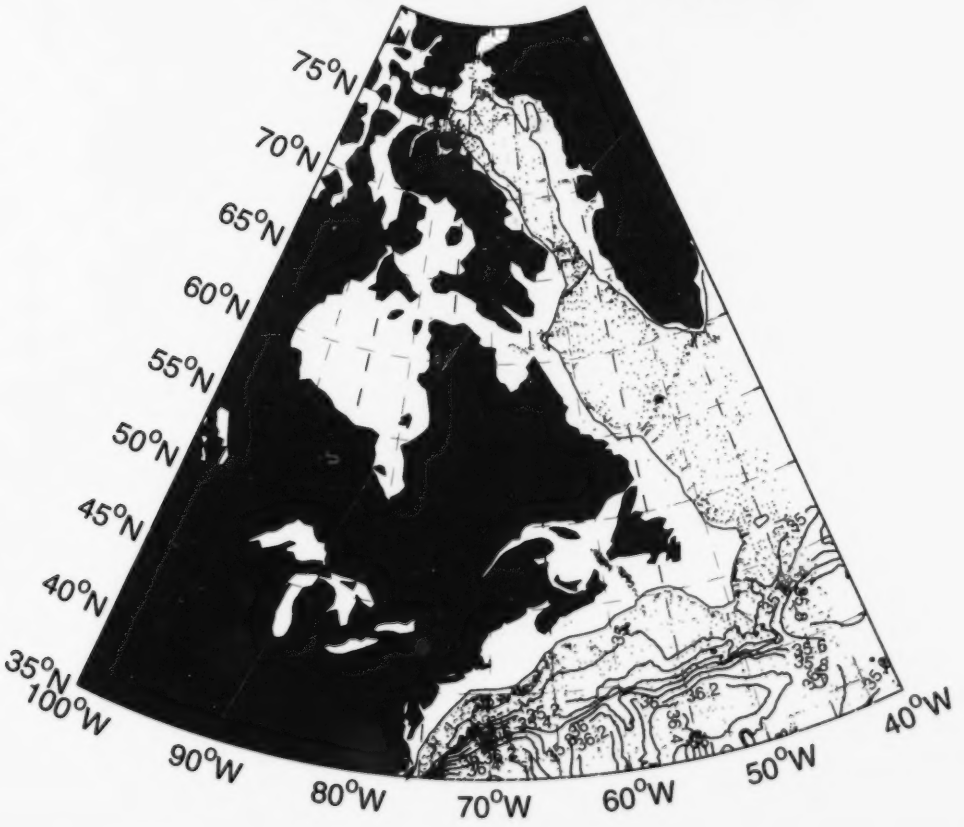
August Salinity at 100m



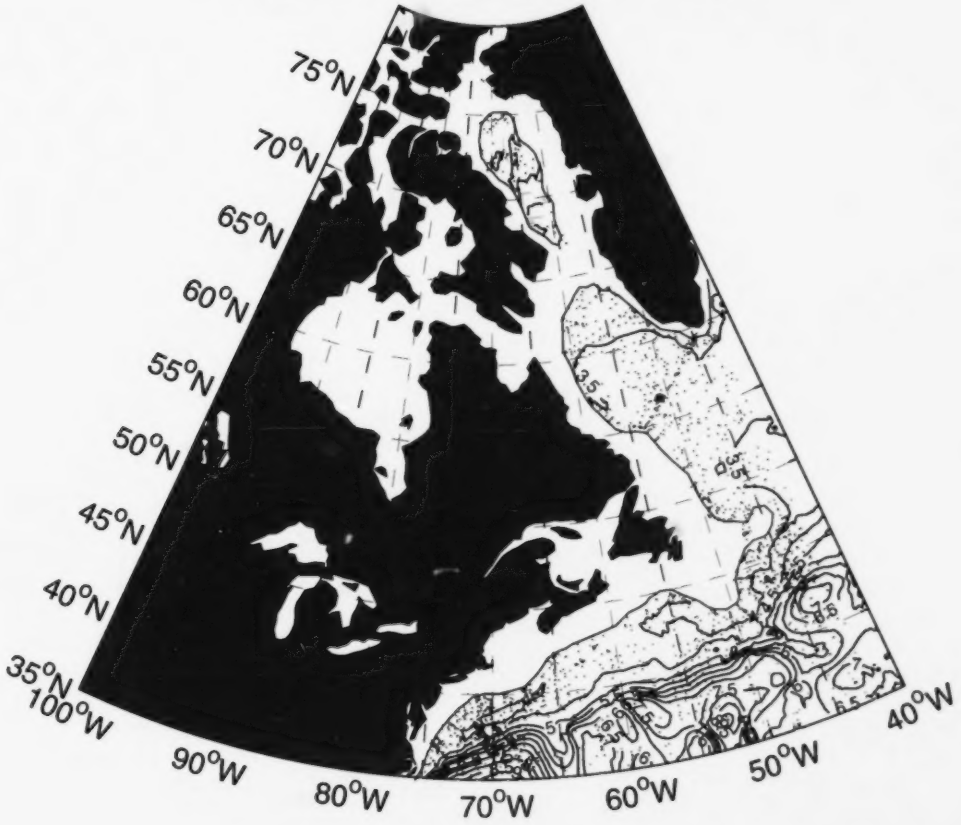
August Temperature at 500m



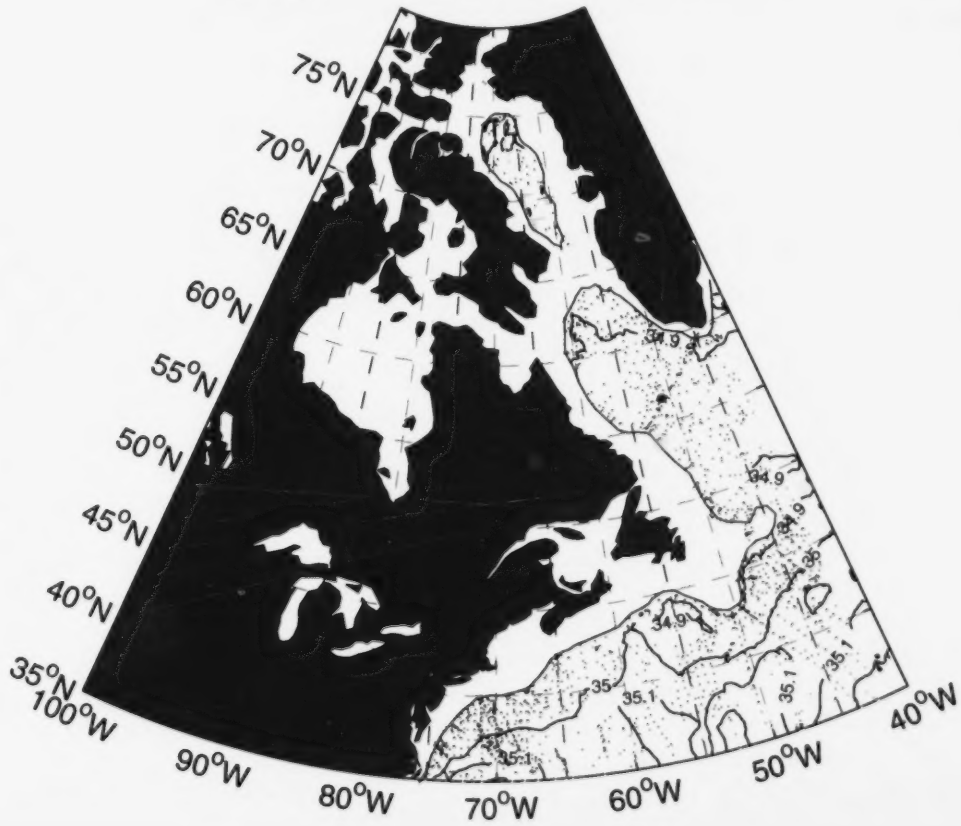
August Salinity at 500m



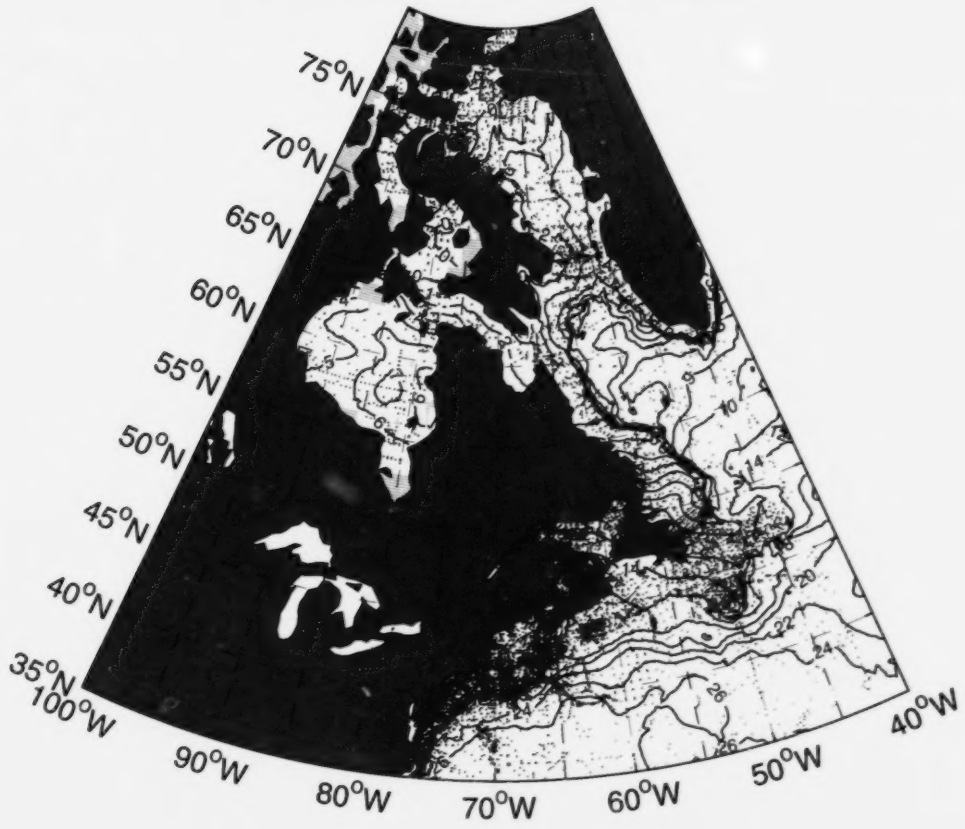
August Temperature at 1000m



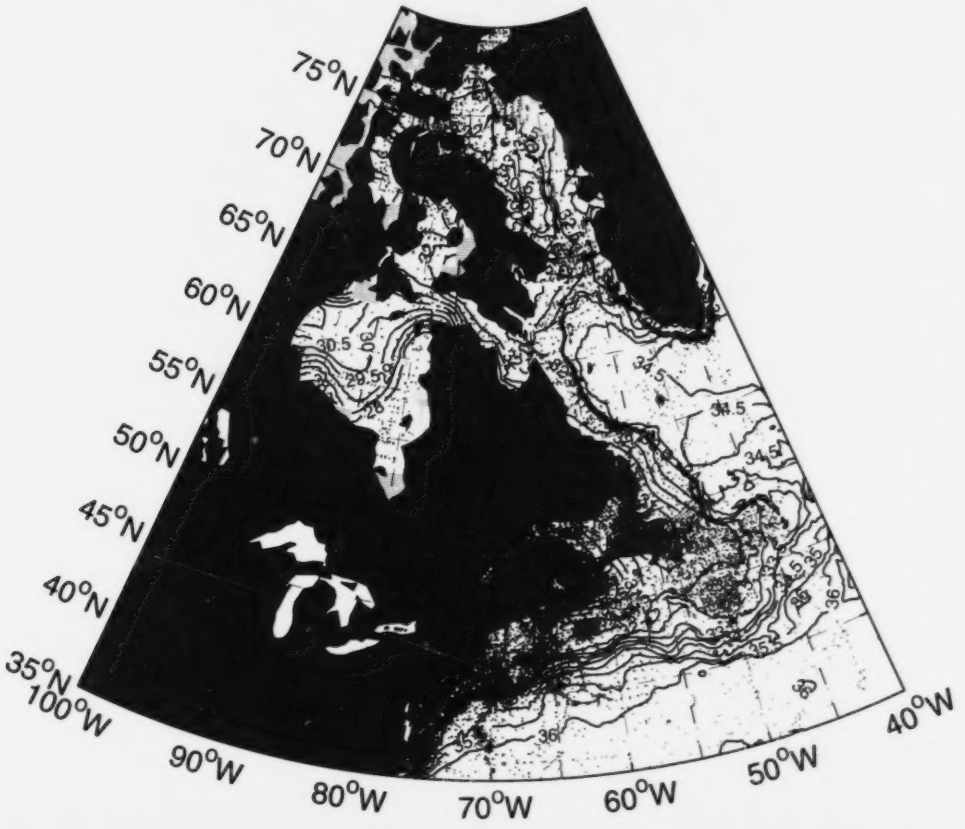
August Salinity at 1000m



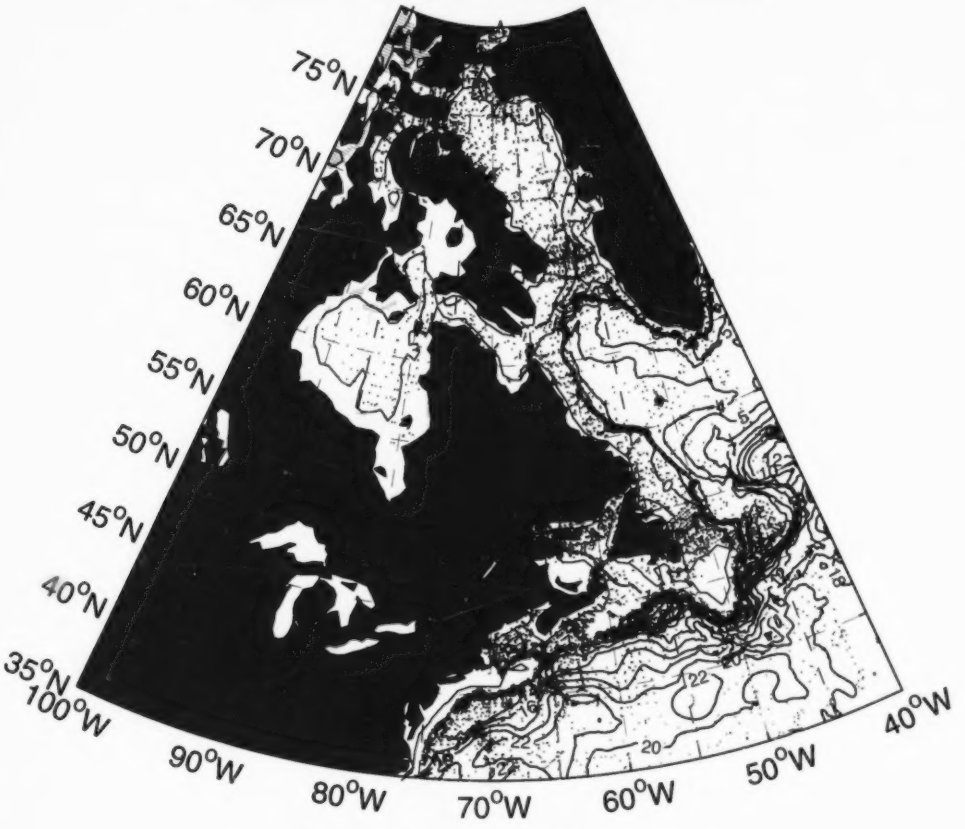
SeptemberTemperature at 0m



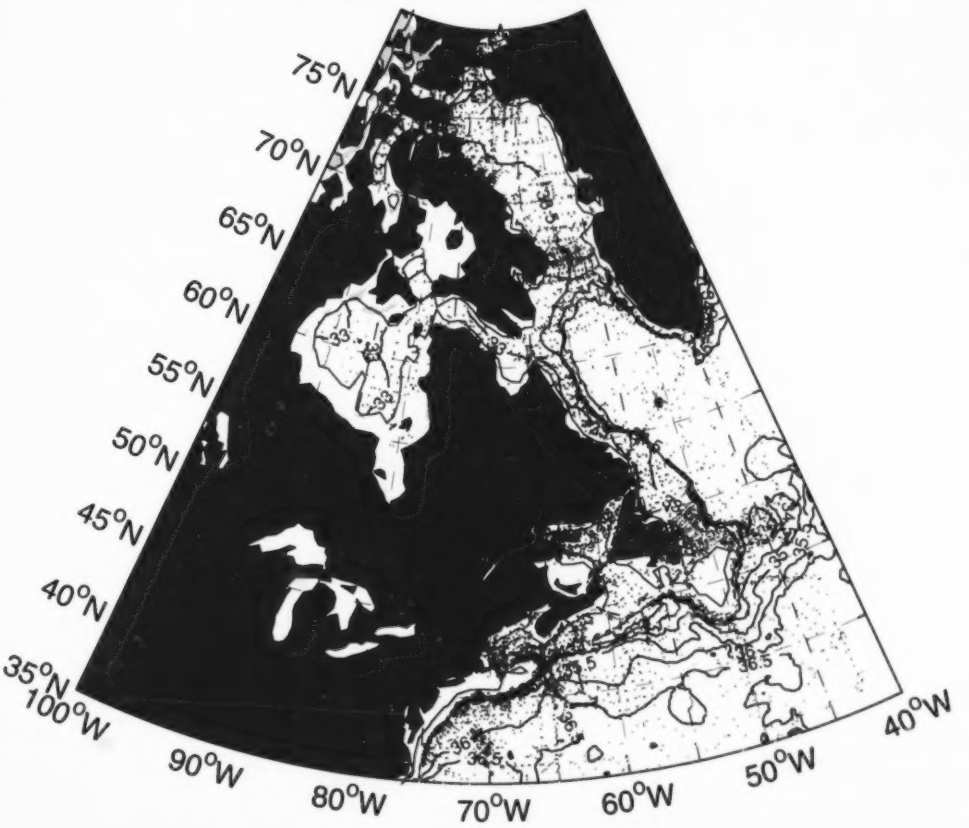
September Salinity at 0m



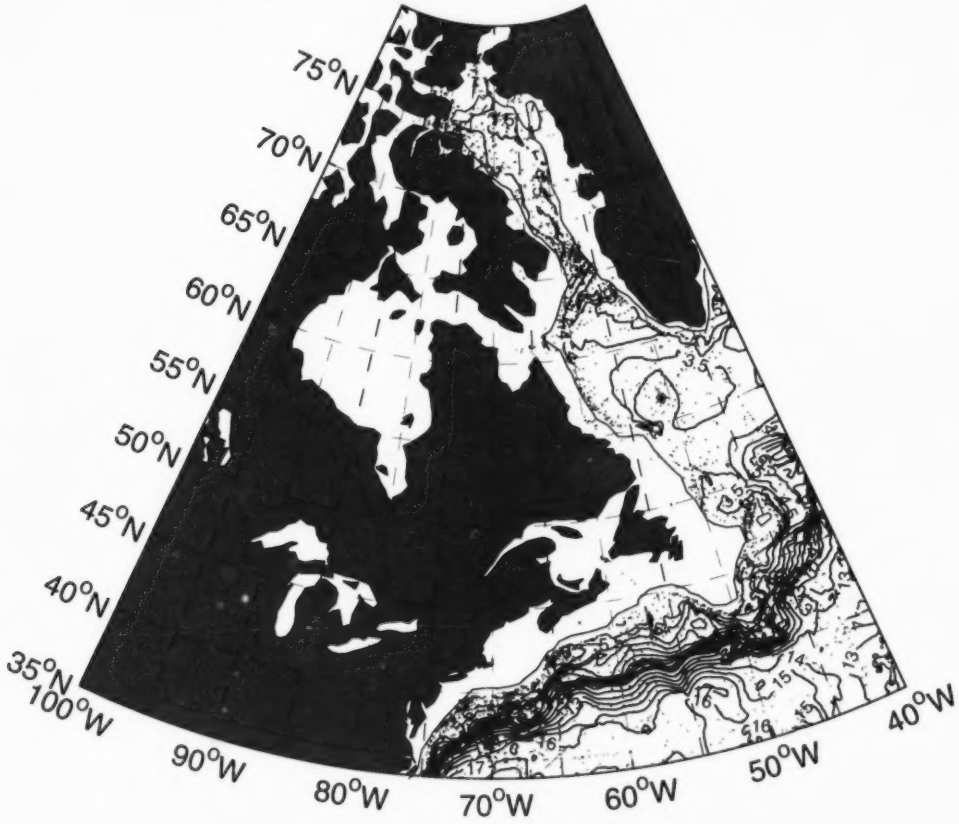
SeptemberTemperature at 100m



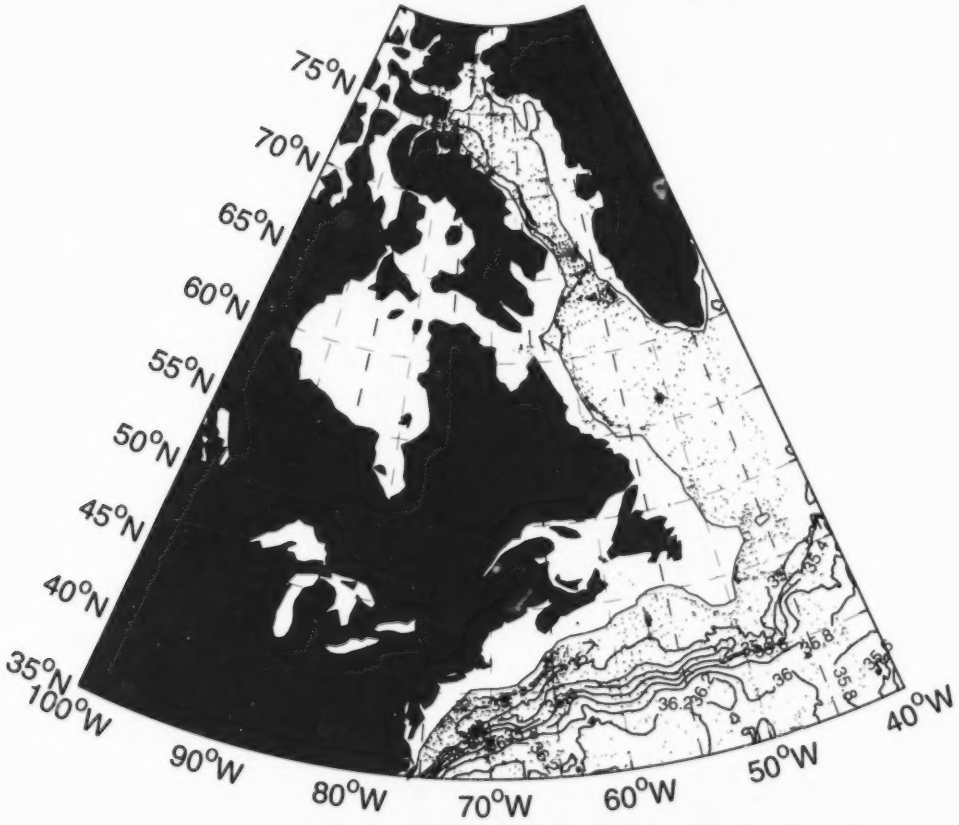
September Salinity at 100m



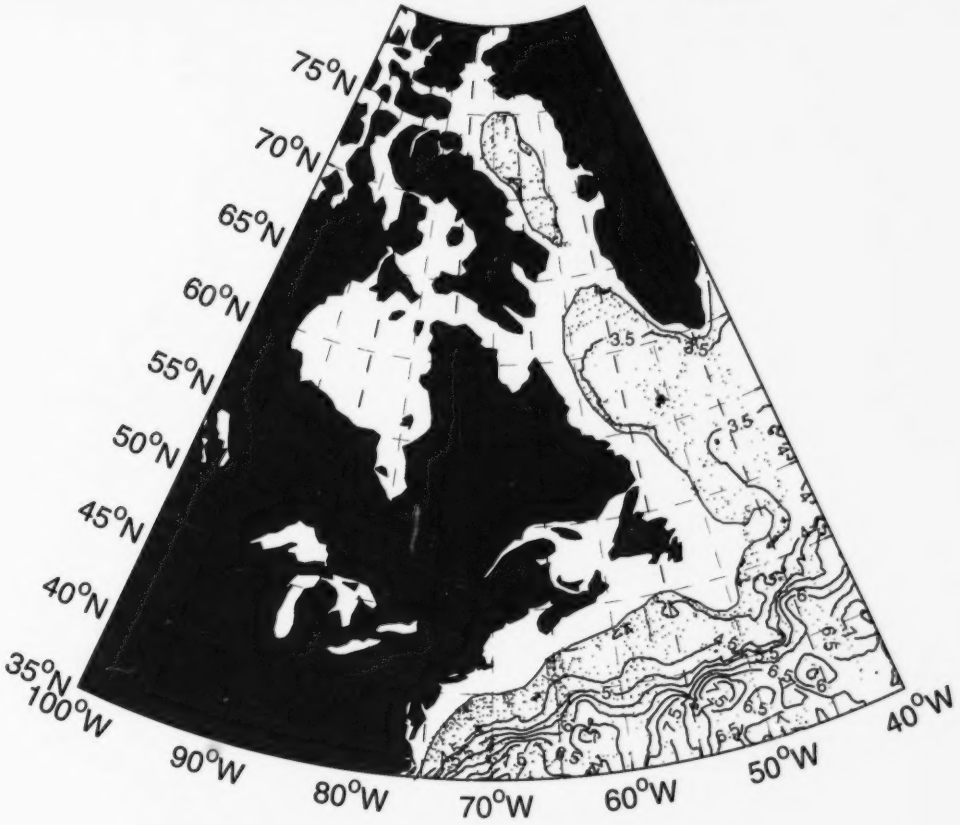
SeptemberTemperature at 500m



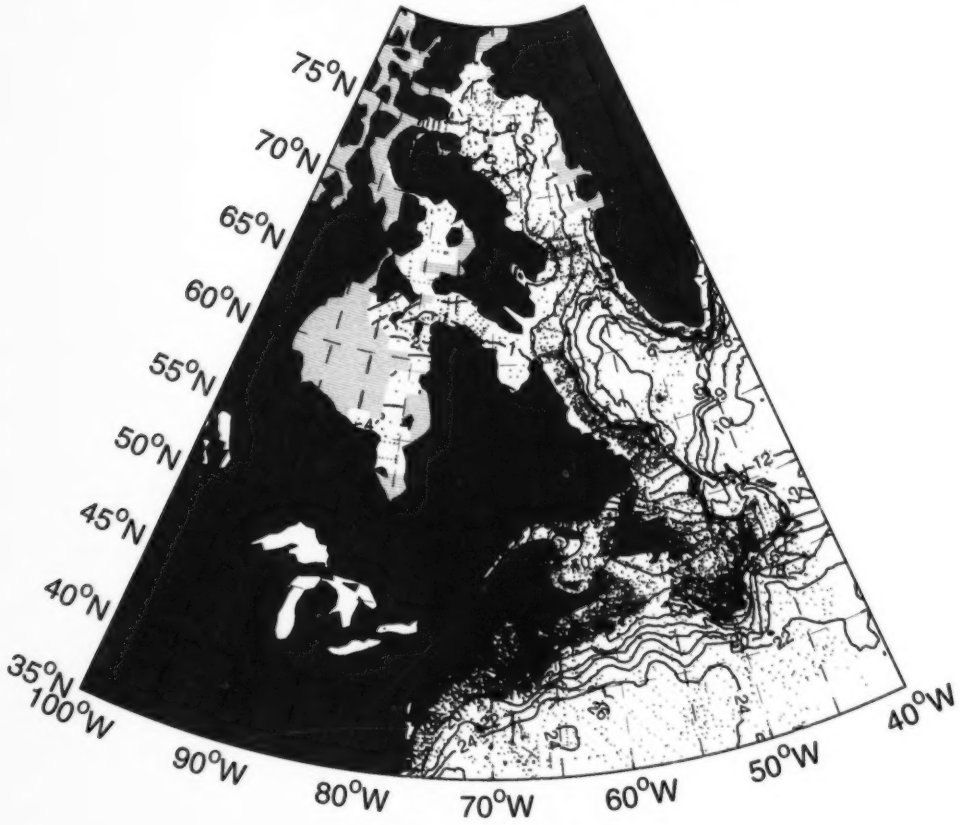
September Salinity at 500m



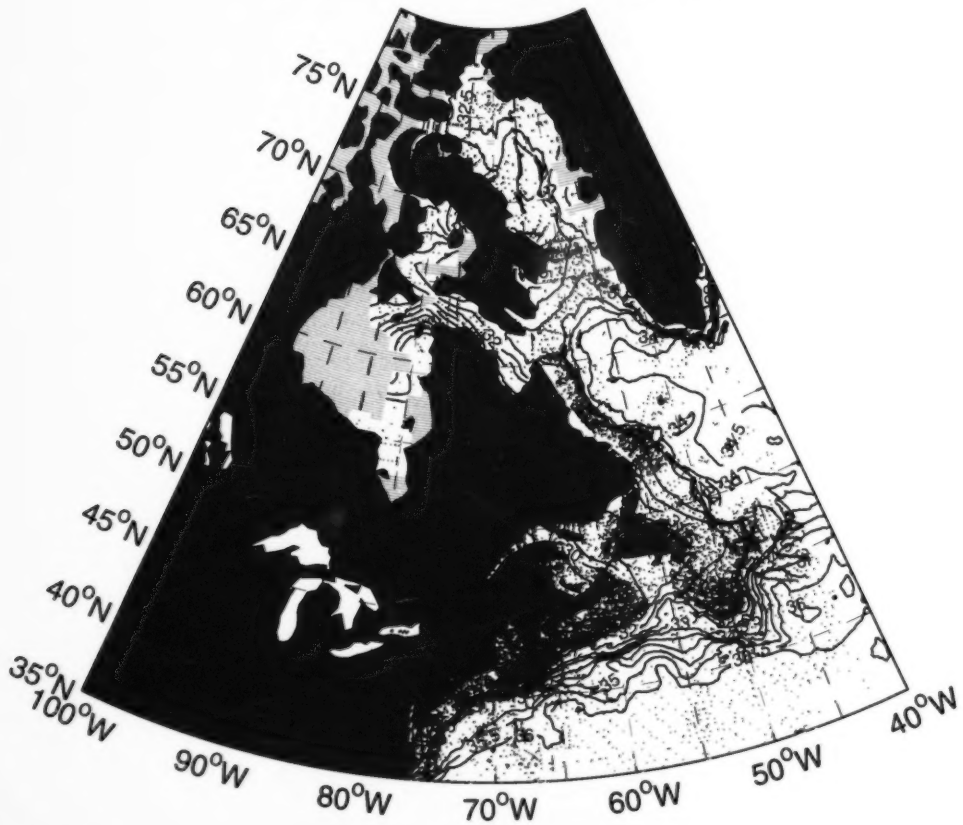
SeptemberTemperature at 1000m


75°N
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
100°W
90°W
80°W
70°W
60°W
50°W
40°W
3.5
3.5
3.5
4
4.5
5
5.5
6
6.5
6.5
6.5

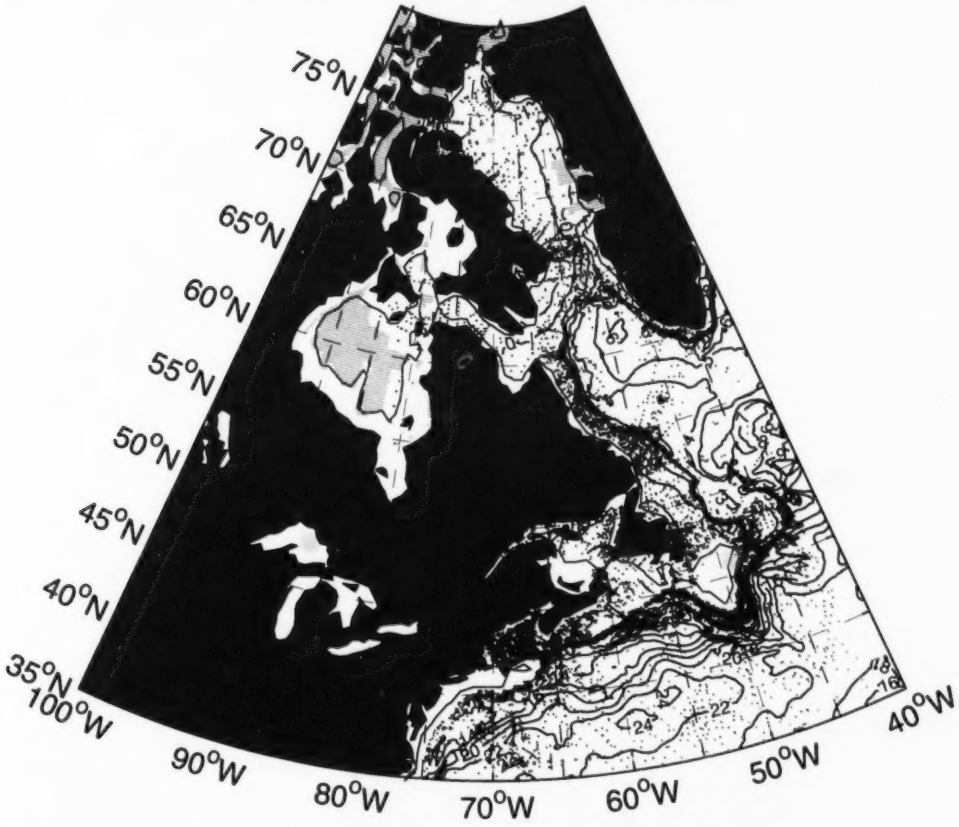
October Temperature at 0m



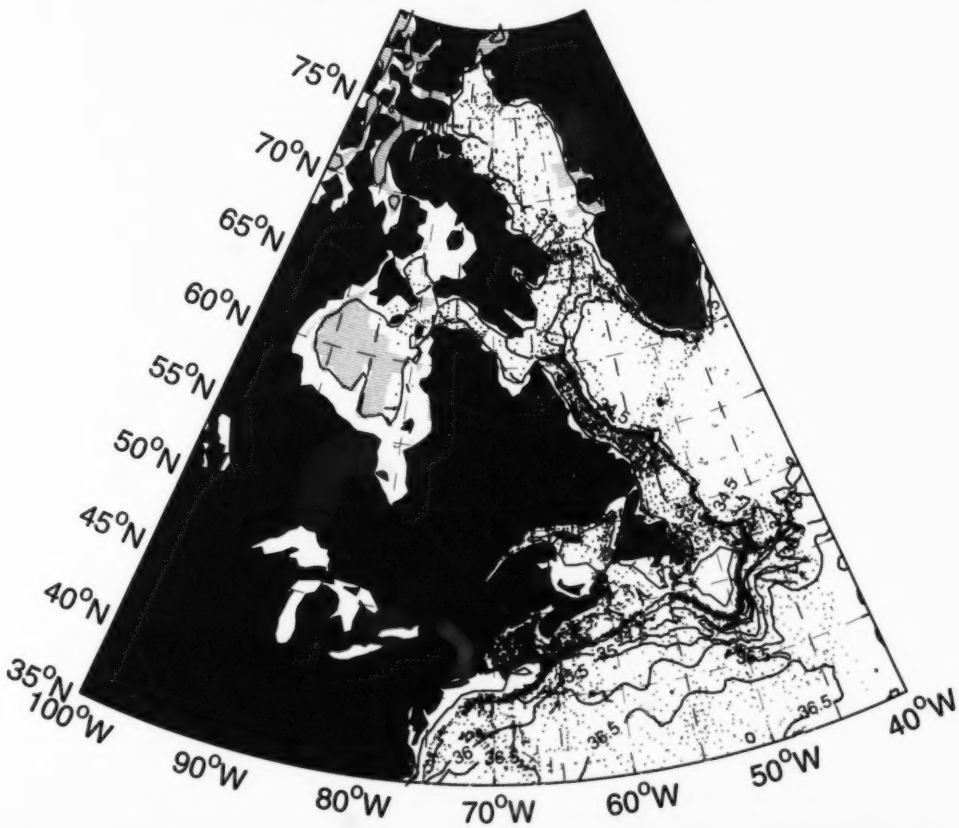
October Salinity at 0m



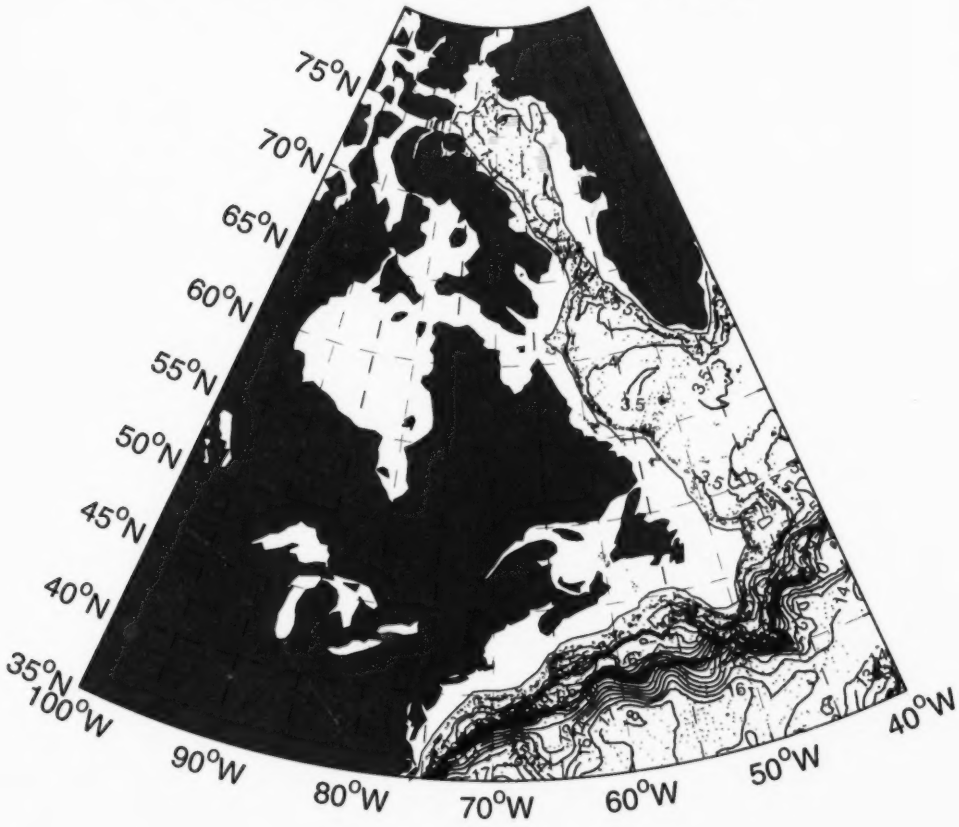
October Temperature at 100m



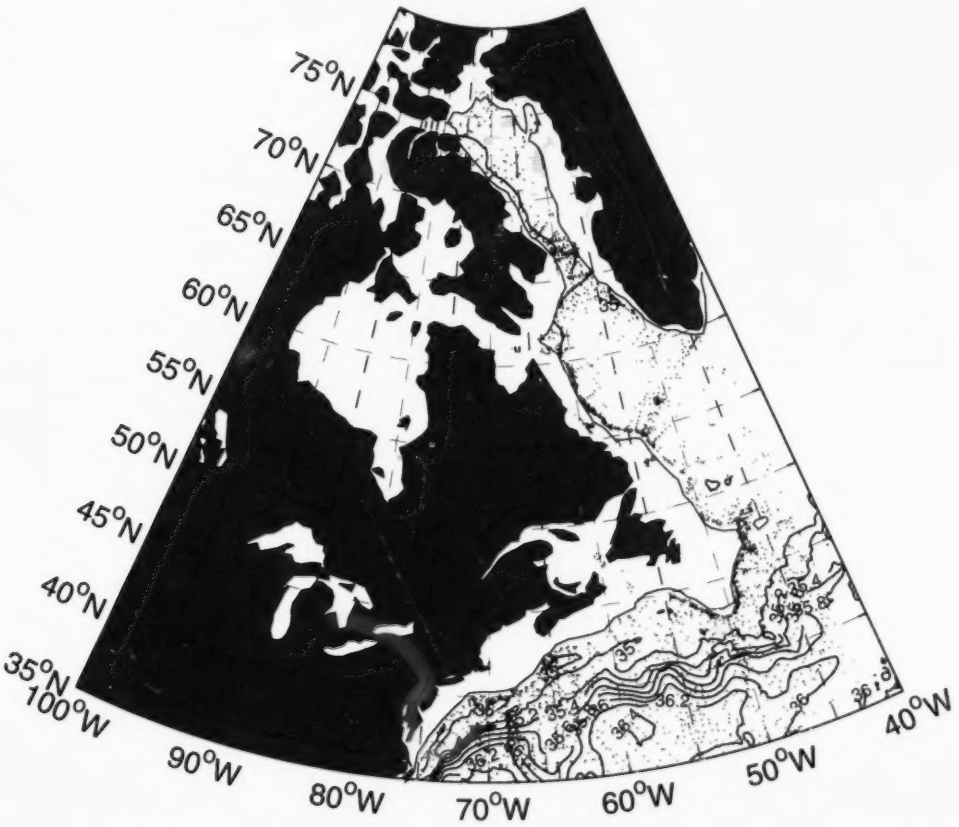
October Salinity at 100m



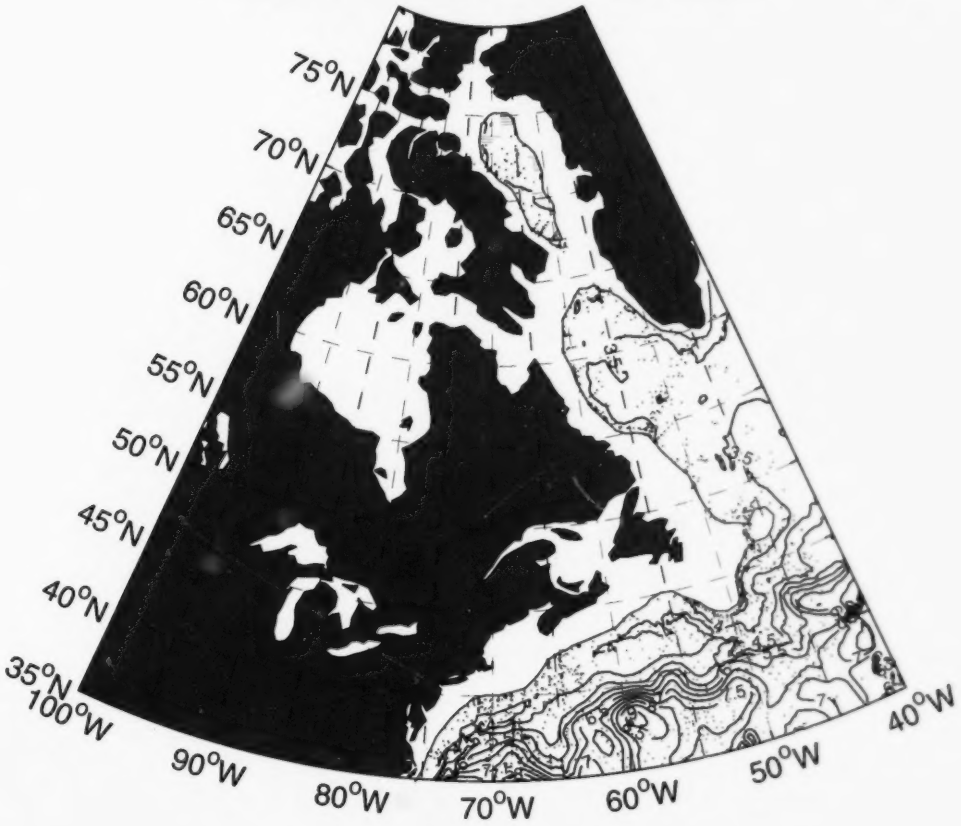
October Temperature at 500m



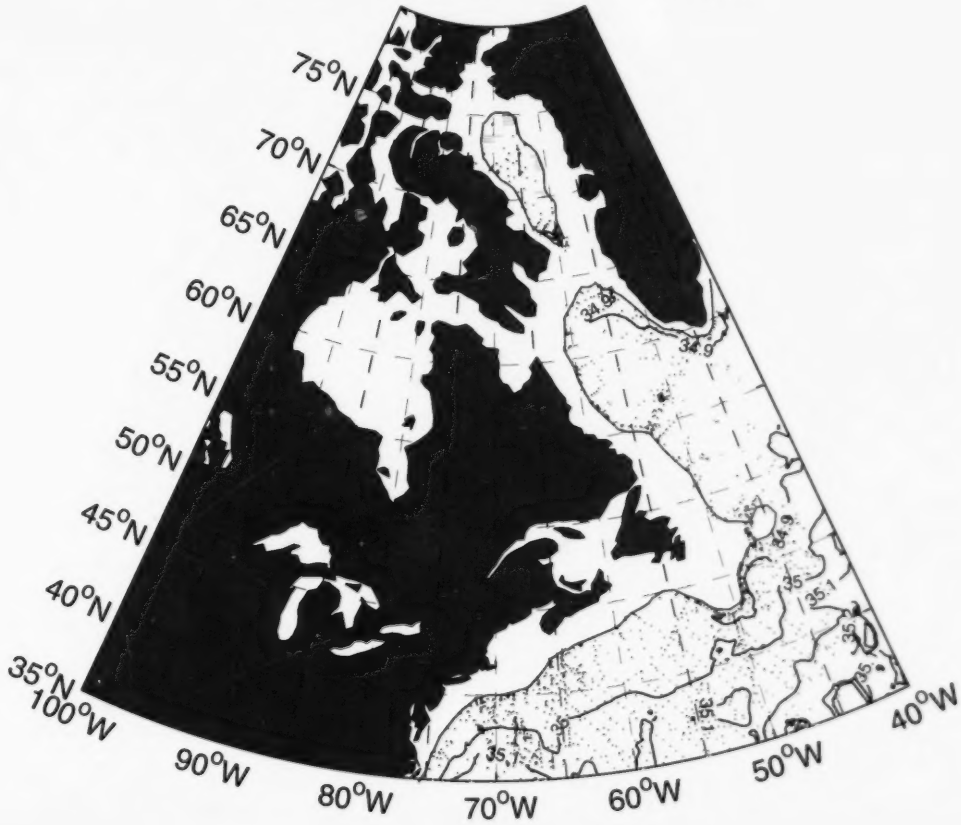
October Salinity at 500m



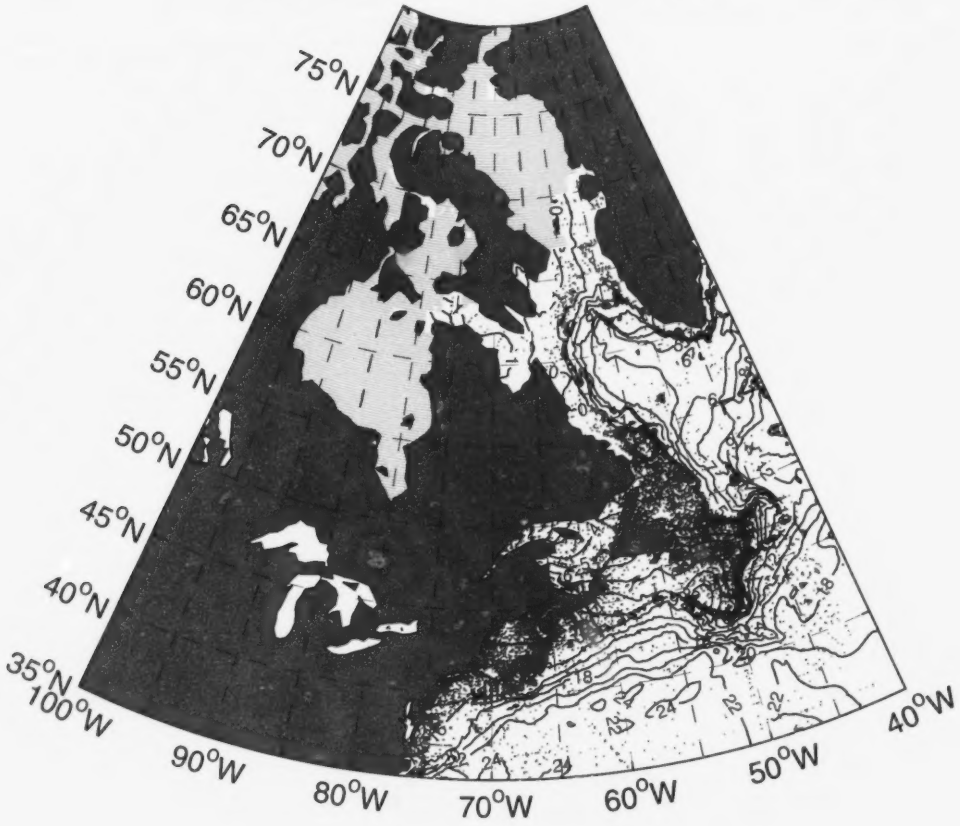
October Temperature at 1000m



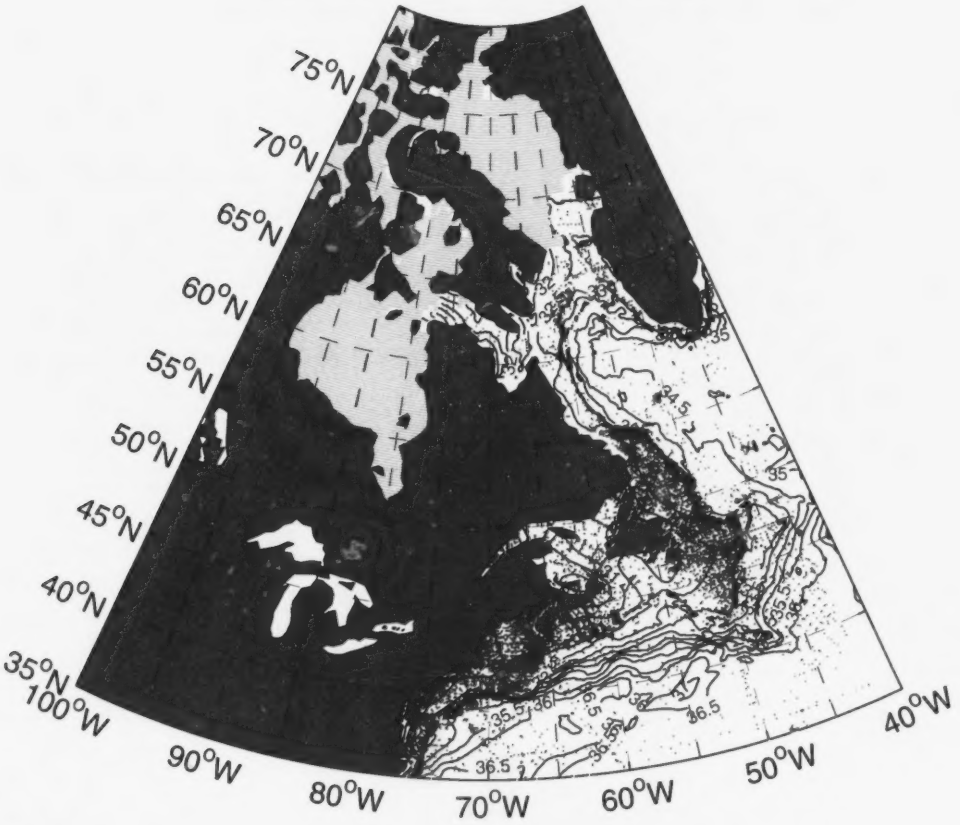
October Salinity at 1000m



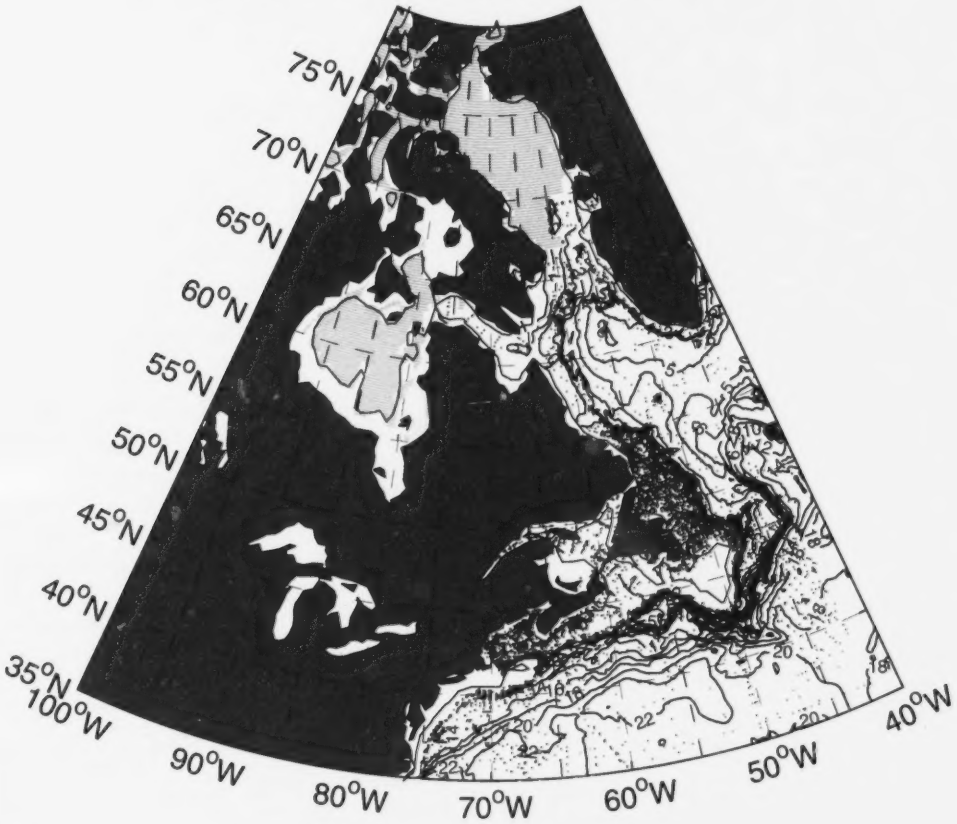
November Temperature at 0m



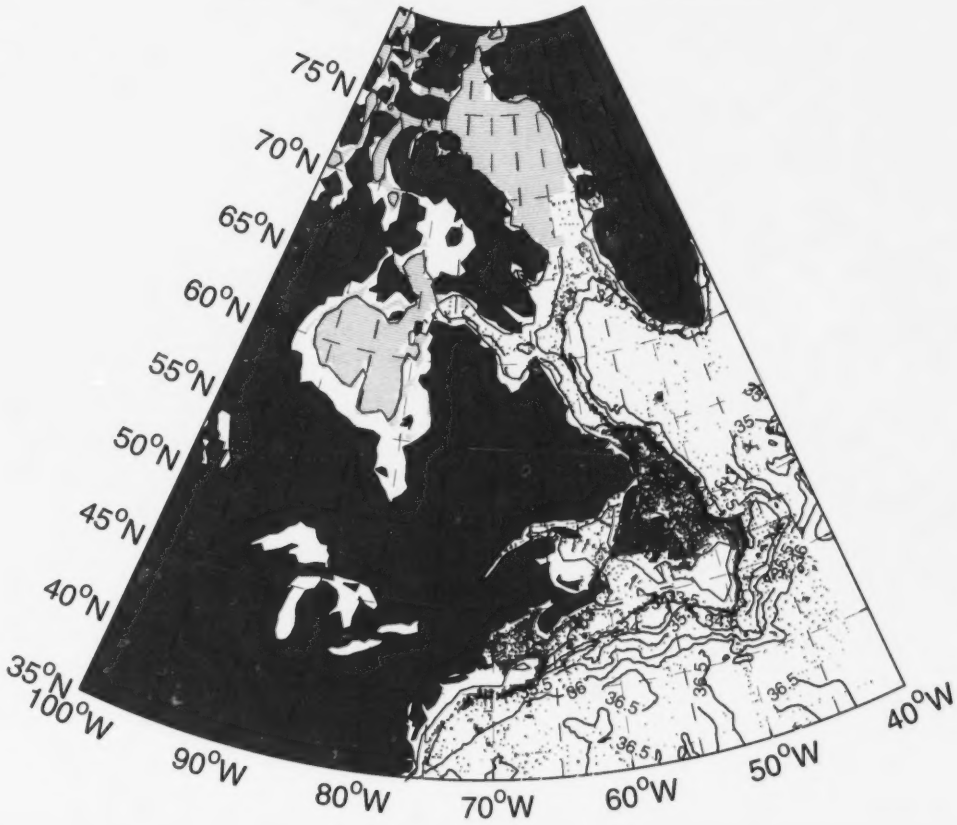
November Salinity at 0m



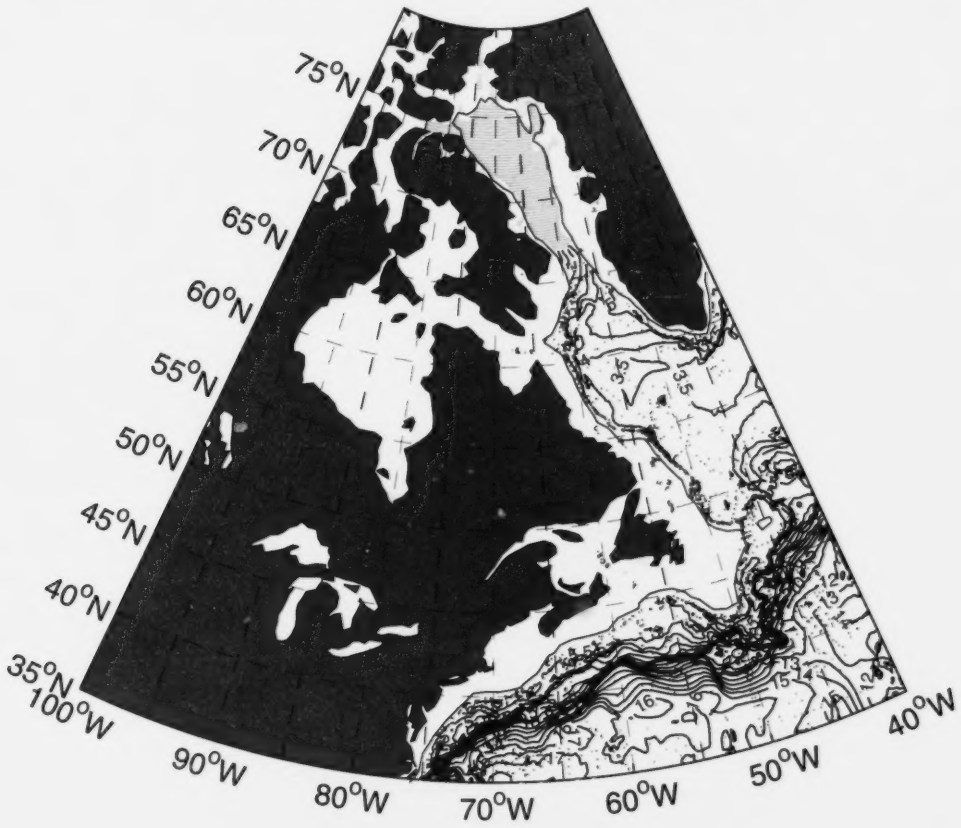
November Temperature at 100m



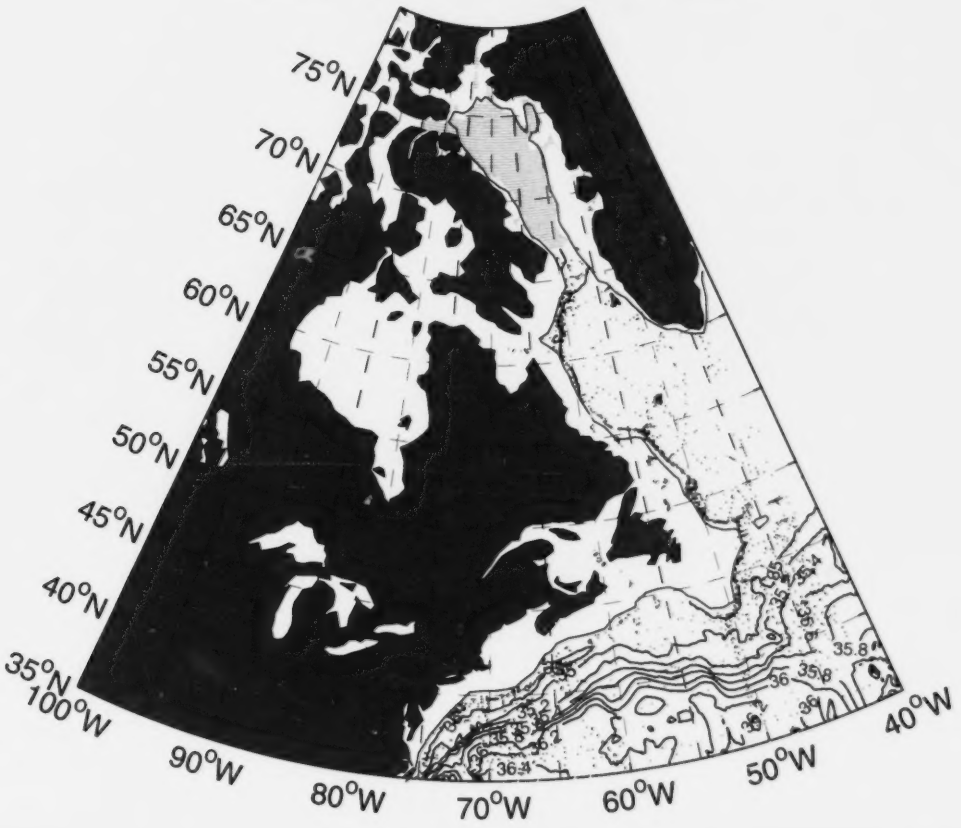
November Salinity at 100m



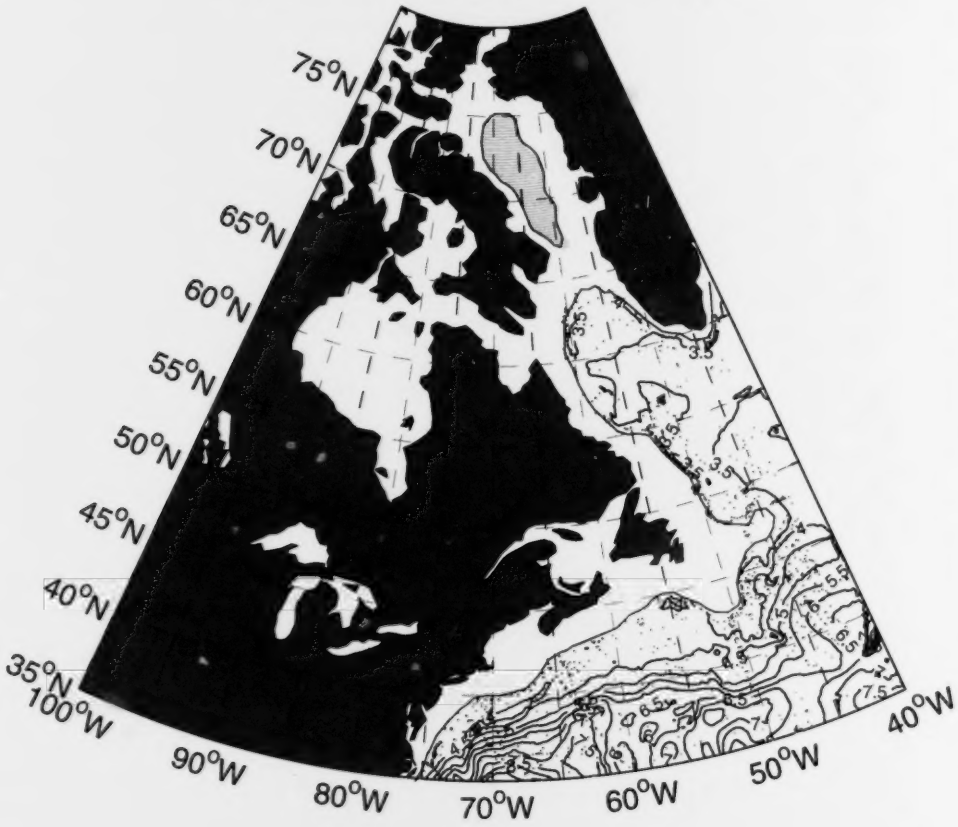
November Temperature at 500m



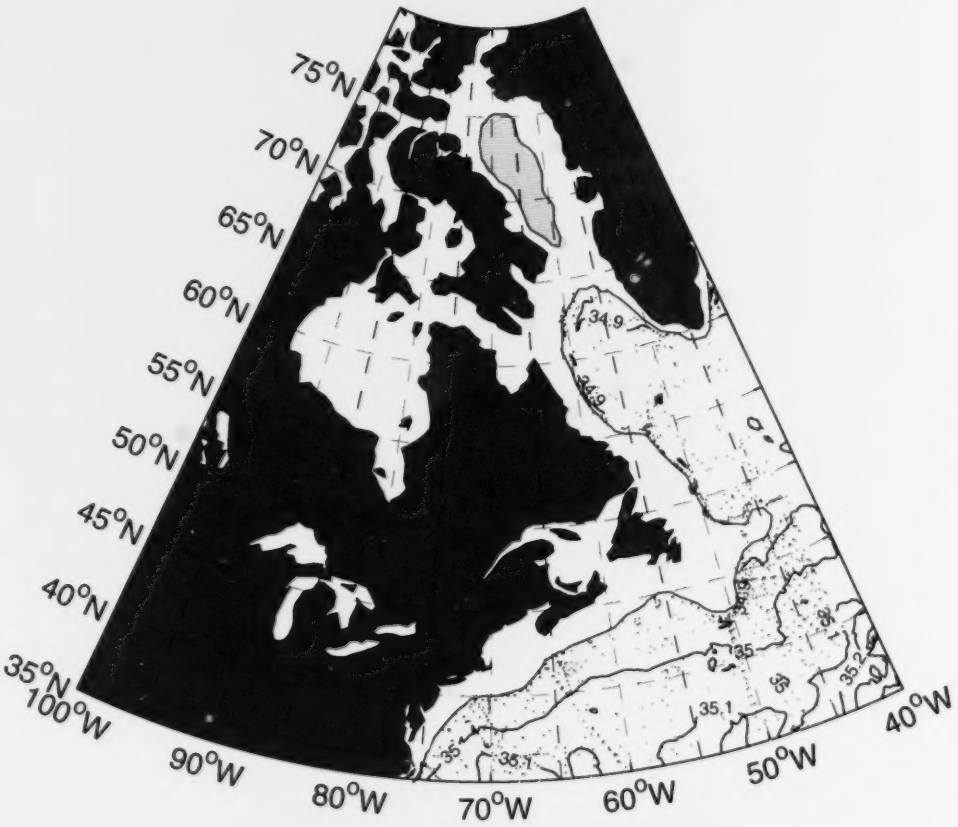
November Salinity at 500m



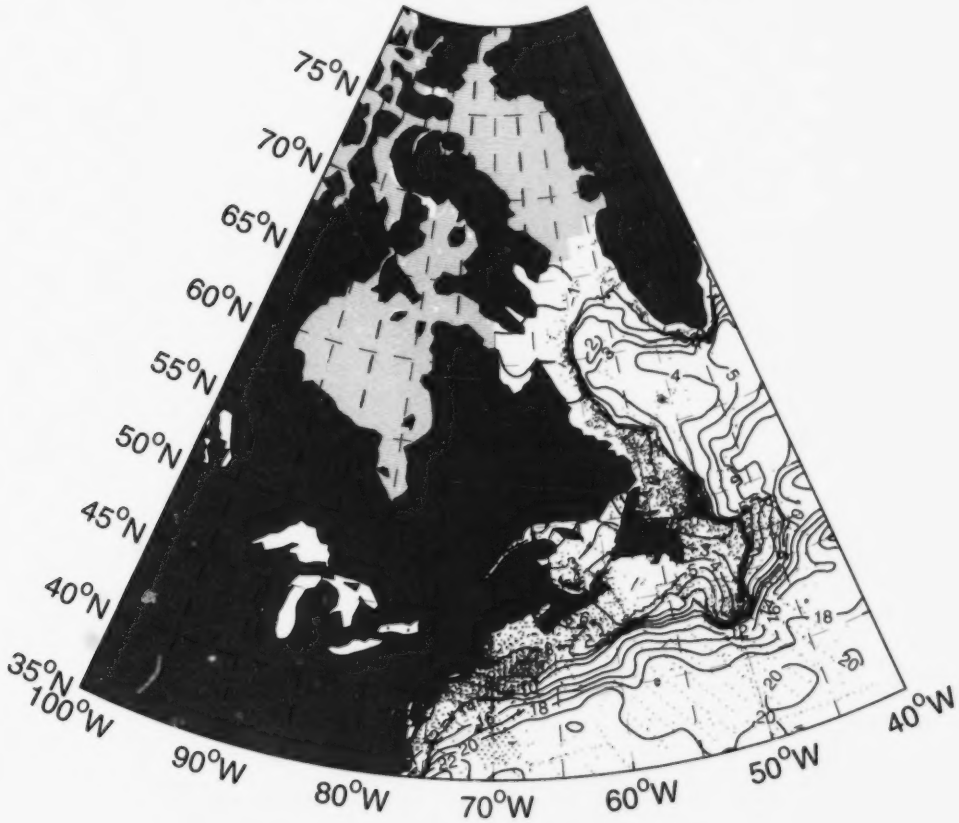
November Temperature at 1000m



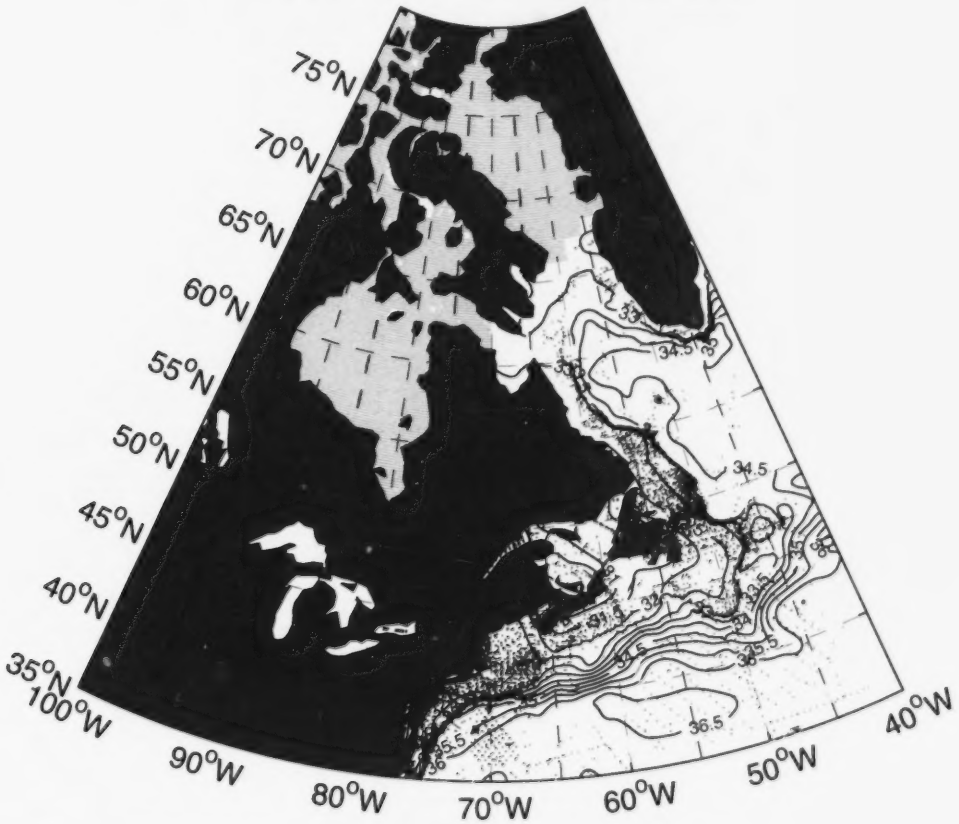
November Salinity at 1000m



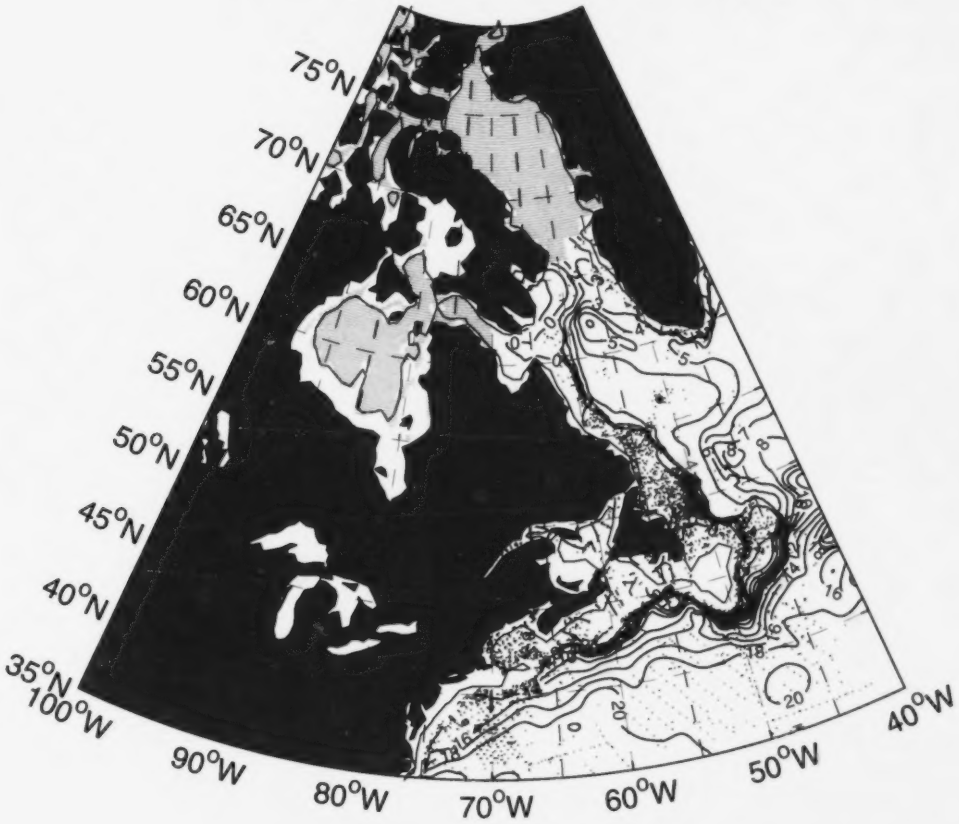
December Temperature at 0m



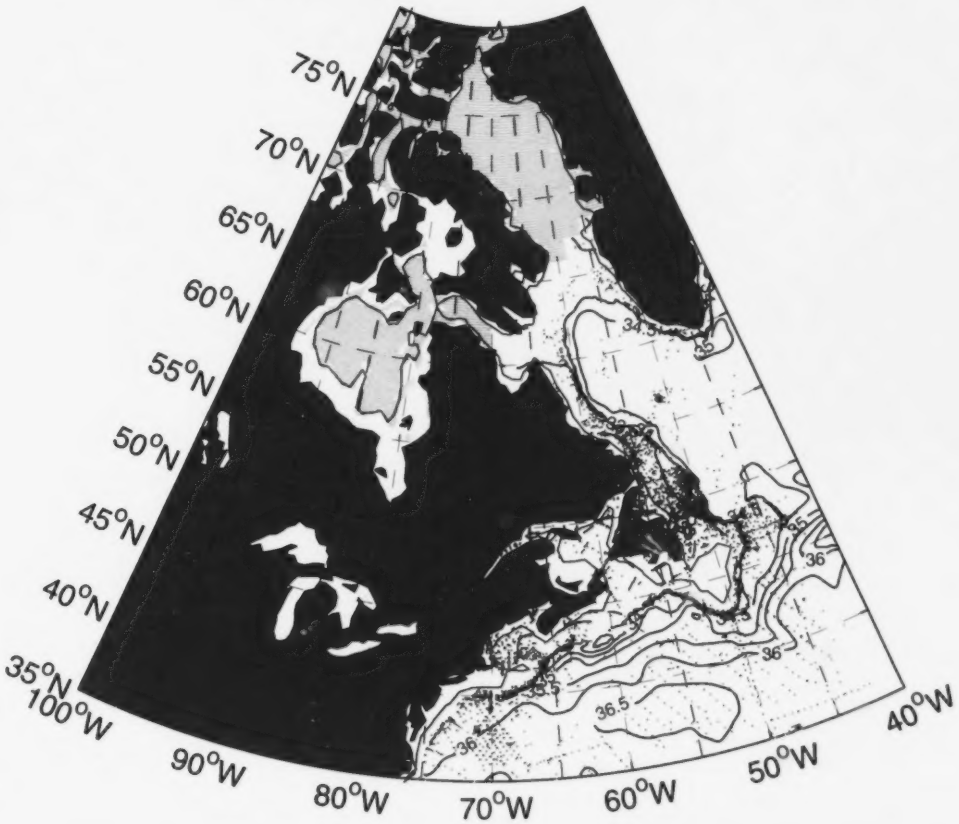
December Salinity at 0m



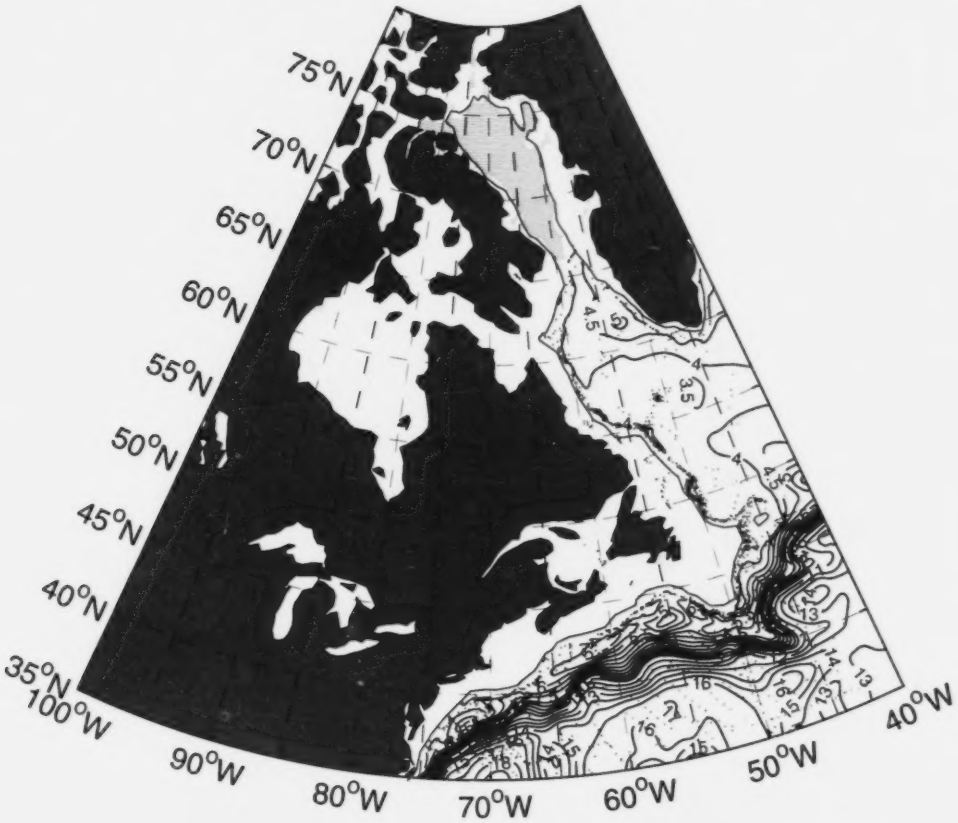
December Temperature at 100m



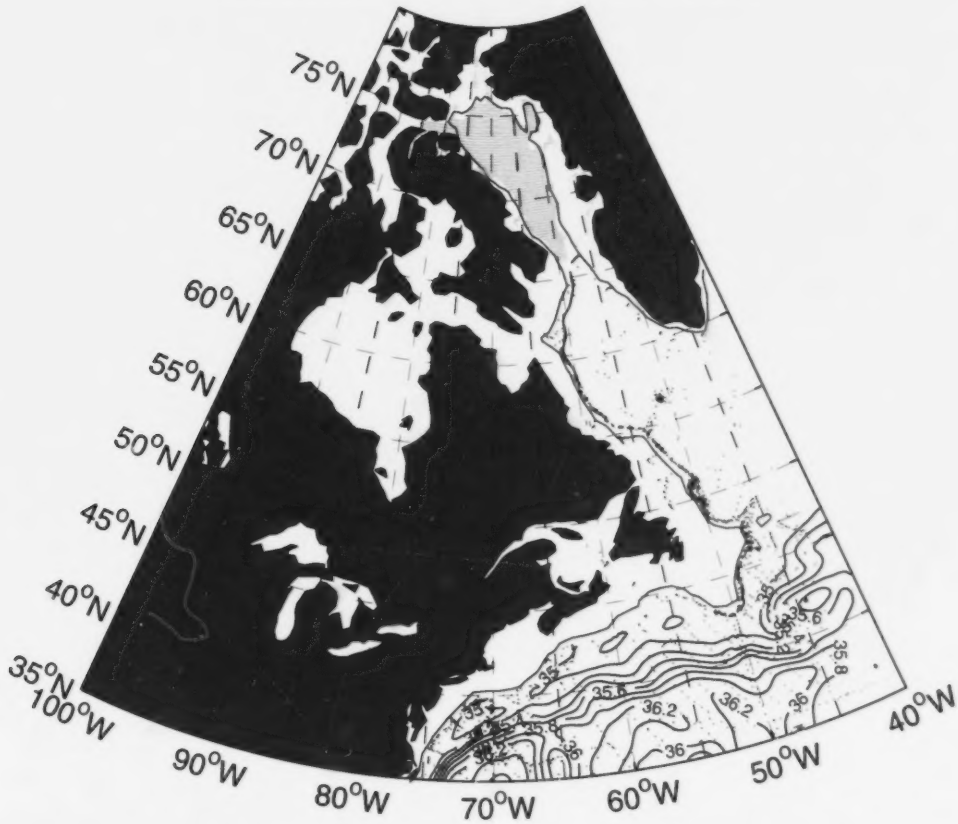
December Salinity at 100m



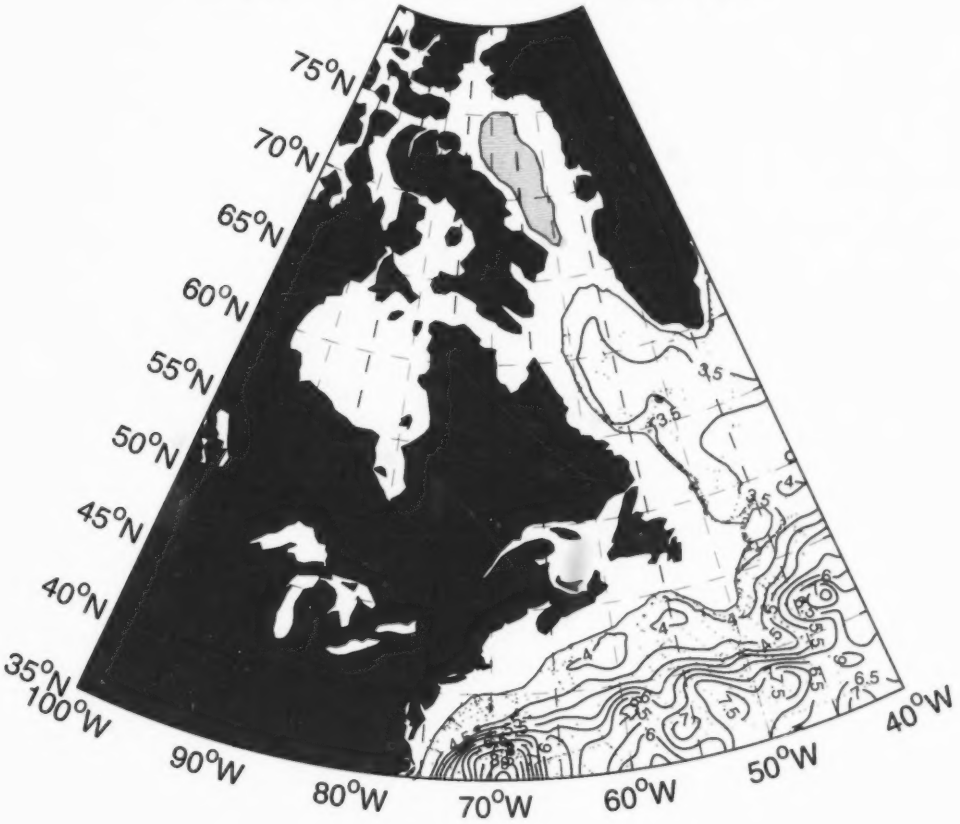
December Temperature at 500m



December Salinity at 500m



December Temperature at 1000m



December Salinity at 1000m